Venture capital investing and the "Calcutta Auction"

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Abstract

Rational models of firm valuation hold that the value of a firm derives from its future earnings. These valuations are grossly exceeded under certain circumstances such as when a potential market is first uncovered and there is only a short time frame for entrants to get into this market. The entrants are fully aware that as few as one (or even zero) firms might survive in this market. Further, investments by different firms tend to work together to develop the market, since entry, investment, and expansion help give the market credibility and bring in the first customers. The wave of investments in Internet-related businesses in the late 1990s is such an example.

In this paper, we argue that the investment decision in such circumstances can be modeled as a "Calcutta auction." The Calcutta auction is a mechanism that fits nicely with venture capital investment dynamics and that leads to some non-obvious results. Based on this model, investments by venture capitalists and other professional investors follow a relatively simple formula that might be considered to be the "optimal bid" in a Calcutta auction. We derive several theoretical propositions on the nature of bidding in electronic markets and illustrate the mechanism using data from 10 industries involved in Internet-based businesses. A consistent pattern of behavior emerges from the application of the model indicating that investors may have been much more rational than previously thought.

(Venture Capital; Calcutta Auction; Rationality; Electronic Markets)

INTRODUCTION

Rational models of firm valuation hold that the value of a firm derives from its future earnings. These valuations are grossly exceeded under certain circumstances. Probably, most significantly when a potential market is first uncovered and there is only a short time frame for entrants to get into this market. The entrants are fully aware that as few as one (or even zero) firms might survive in this market. Further, investments by different firms tend to work together to develop the market, since entry, investment, and expansion help give the market credibility and bring in the first customers. The wave of investments in Internet-related businesses in the late 1990s is such an example.

Consider, for example, the investment in the Internet-based pet supply industry during the late 1990s. Total investments in firms offering pet supplies over the Internet were $352 million and $45 million in 1999 and 2000, respectively. The sales-to-capital ratio in the pet supply industry was approximately 30 in the late 1990. Furthermore, total industry sales during the same period, based on Compustat data, was approximately $1.6 billion per year. In calculating the incremental sales expected to justify the 1999 investment, it appears that Internet-based sales should equal, $352M x 30 or $10.6 billion, implying total industry sales of about $12.1 billion rather than the current $1.6 billion. The projected increase in sales of $10.6 billion is a conservative estimate (if all the investments bear fruit) for several reasons. First, the venture capital (VC) investment in an industry does not represent the entire capital invested in it.[1] Nor does it include prospective future investments. It also does not account even for the capital invested by the start-up "owners" of a firm because the firm's senior management must already have invested money and sunk effort before going to the VC. Second, an upward trend in the

[1] For example, pets.com raised $82.5 million in their IPO in February, 2000. This number is not included in our calculation. If one fifth of venture-backed firms go public (Gompers & Lerner, 1999), one gets a sense for how conservative this estimate is.

sales-to-capital ratio implies that productivity has improved over time (more sales generated per dollar of investment in plant and equipment, for example).[2] As investments take time to come to fruition (generate more sales revenue), a "rational" investor might expect even higher sales than the current multiple of 30.

Another possibility with a similar conclusion is from the point of view of profitability. If there must be commensurate return on investment for the risk in the industry, then the sales must grow (assuming the margins remain more or less the same) or the margins should widen substantially. Given few radical breakthroughs in cost reduction due to supply chain reconfiguration (notably Dell Computers, Cisco, Fedex, and eBay) due to the use of digital technology, it seems safe to conjecture that cost savings at the margin that will result in tripling or quadrupling of the gross profit are unlikely. Even if they were likely, these gains could come under attack due to competition.

Similar (but less dramatic) patterns hold for some industries as well as Internet markets as a whole, see Table 1. For example, using the same calculation, the sales expected to justify the 1999 investment in e-commerce software is $5.8 billion against total industry sales of approximately $3.5 billion in 1999. In Internet-based sporting goods, the sales expected to justify the approximately $179 million investment would be a $1.1 billion increment against industry sales of $335 million. In Internet-based biotech/pharmaceuticals, however, there appears to be more rational investment based on this method of calculation: $5 billion increment on total industry sales of approximately $183 billion.

In the economy as a whole, $90.5 billion was invested by venture capitalists (the majority of which was invested in Internet markets) in 2000 (CNN, 2001). Further, the domestic sales-to-

[2] One counterargument is that the trend in sales is also sharply higher. However, if one fits a line to the trend, even five years out (2004 estimate), the total industry sales would be expected to be only $5.2 billion.

capital ratio was approximately 8.6 and total gross domestic product was $8.9 trillion (US Department of Defense, 2000; US Bureau of the Census, 2000) in 1999. Thus the increase in GDP expected from the total venture capital invested would be about $800 billion, or almost 9%. Past explanations for this phenomenon have centered on market myopia, technology racing, herding and free cash flow theories. We briefly review each of these explanations before presenting our model.

Market myopia. Salhman and Stevenson (1986) describe the venture capitalists' (VCs') foray into the Winchester disk drive industry. During the late 1970s and early 1980s, nineteen disk drive companies received venture capital financing. Two-thirds of these investments came between 1982 and 1984, the period of rapid expansion of the venture capital industry. Many disk drive companies also went public during this time. While industry growth was rapid (sales increased from $27 million in 1978 to $1.3 billion in 1983), Salhman and Stevenson question whether the scale of investment was rational given any reasonable expectations of industry growth and future economic trends. They suggest that "market myopia" (irrationally short-term view of the market) affected the VC investments. They claim that individual investments may have been rational but individual investments conditioned on everyone else's investments were short-sighted or irrational.

Technology races. Lerner (1997) suggests that disk drive manufacturers may have displayed behavior consistent with strategic models of "technology races," in which firms that are behind expend more effort to overtake rivals and claim the indivisible, winner-take-all prize. One interpretation of this is that as firms had the option to exit the competition to develop a new disk drive, it may have been rational for venture capitalists to fund a substantial number of disk drive manufacturers. If the VCs saw that the firms were clearly losing, the VCs would have stopped funding the project. Similar interpretations have been made regarding investments in software, biotechnology, and the Internet. The phrase "too much money chasing too few deals" is a common refrain in the venture capital market during periods of rapid growth.

Herding. Several researchers argue that institutional investors frequently engage in "herding:" making investments that are too similar to one another (Devenow and Welch, 1996). These models suggest that a variety of factors — such as when the assessment of performance is on a relative rather than an absolute basis — can lead investors to obtain poor performance when making too many similar investments. As a result, "social welfare may suffer because value-creating instruments in less popular technological areas may have been ignored" (Gompers and Lerner, 1999, p. 137).

Devenow and Welch propose three main reasons for "rational" herding behavior: (1) payoff externalities, in which payoffs to an action increase in the number of other people who also adopt the same action; (2) principal-agent issues, which refers to managers attempting to avoid evaluation by "standing out"; and (3) cascade models, where managers override their own private information and assume that prior actions by others reveals more valuable information in the absence of others' private information. It might be argued that each of these explanations has a bit of irrationality in it.

Cash flows. Jensen (1986) proposes that managers prefer to keep cash windfalls within the firm to retain control of the firm. He presents data from the oil industry that indicates that firms invested large cash surpluses excessively in exploration and development activities in the early 1980s. Jensen's approach implies that VCs that are flush with cash from earlier successful investments might be tempted to make further investments instead of keeping the cash in the bank. Note however that the free cash flow theory will not hold as strongly when managers are the owners of the firm.

The present approach

In this paper, we argue that the investment decision in the circumstances outlined in the introduction can be modeled as a "Calcutta auction" (see below). The Calcutta auction is a mechanism that fits nicely with venture capital investment dynamics and that leads to some non-obvious results. Based on this model, investments by venture capitalists and other professional investors follow a relatively simple formula that might be considered to be the "optimal bid" in a Calcutta auction. We illustrate this mechanism using data from 10 industries and 81 firms involved in Internet-based businesses. A consistent pattern of behavior emerges from the application of the model indicating that investors may have been much more rational compared to the explanations offered above.

We also identify a new role for very early stage investors which we call "seeding the pool." Even though early stage investors (such as angel investors [wealthy individuals that invest their own funds in the early stages of ventures] or early-stage VC funds) may simply try to maximize their own company's chance of winning in the market, by their actions, they may be attracting VC funds to the industry as a whole as the market develops. This may or may not help the original startup but helps fuel the growth of that industry. One of our key conclusions is that higher valuation relative to the classical methods of firm valuation may not actually be irrational. We develop new measures for understanding when there is under- or over-investment based on the total investment in an industry.

The paper is structured as follows. Some background on the Calcutta Auction is provided in the next section. We then describe a model of the auction, including an analysis of bids. We show that our model helps predict the flow of capital into ten Internet-based industries using data from the VentureSource database on startup companies and their venture capital funding. We conclude the paper with a discussion of rationality and exuberance.

The Calcutta Auction

According to the Webster's Unabridged Dictionary (2000: 296), a "Calcutta" or "Calcutta pool" is "a form of betting pool for a competition or tournament, as golf or auto racing, in which gamblers bid for participating contestants in an auction, the proceeds from which are put into a pool for distribution, according to a prearranged scale of percentages, to those who selected winners." In a Calcutta auction, players compete in a tournament, such as a backgammon tournament. Each player in the tournament is "auctioned off" to the highest bidder. Each bid is then added up to a prize "pool" which is won by the "investor(s)" in the winning player, minus a commission for the organizer. The Appendix contains a detailed history of this auction.

For example, a backgammon tournament might have sixteen players. In addition to the players, there are many bidders (spectators, investors) whose number exceeds the number of players. Before the tournament begins, each of the sixteen players is "put up for auction" where the highest bidder wins the rights to the pool in case her player wins (in an actual tournament, players can also participate in their own auction). Thus each player is "owned" by one bidder. For example, Player 1 could be auctioned off to Jane, with a winning bid of $5000, followed by Player 2 with a bid of $5500 to James, and so on. All of the winning bids (the $5000 plus the $5500 plus the rest) are combined into a pool. If for example, the pool totals to $50,000 and

Player 1 wins in the ensuing tournament, then Jane receives $50,000 minus a (say) 10% commission. Similarly, if Player 2 wins the tournament James wins $50,000 (minus the commission). From the viewpoint of Jane, in the case in which she wins she receives $45,000, minus her initial bid of $5000 for a net gain of $40,000 otherwise she stands to lose $5,000.

Surprisingly, this widely used format of wagering has not been previously analyzed. Today this auction is used mainly in wagering on the winner(s) in games of skill (and not in games of chance — see Appendix for more details).

The analogy to Venture Capital investing

There are many similarities between the Calcutta auction and venture capital investing. The startups are analogous to the players that are about to compete. The venture capitalists are analogous to the bidders, while competing for market share in the common (industry specific) marketplace is equivalent to playing in the tournament. A startup firm's initial public offering is analogous to winning the tournament, as it allows the VCs to realize gains from their investments.[3] In reality, there are often few winners and the development of the market can occur quite quickly with many startups simultaneously developing the technologies or products that they hope will enable them to win once they hit the market (Gompers and Lerner, 1999).

Investments are made based on the probability that the player will win the tournament and the total estimated size of the pool. Just as a gambler attempts to assess the player's skills at backgammon, the VC attempts to ascertain the chance that a particular management team has the skills, experience, and ambition to win in the market. Complicating the analogy is the fact that

[3] We realize that VCs may not be able to (or want to) liquidate their entire holding after an IPO. However, they may be able to sell some and may be able to hedge their position with respect to the rest, allowing them to realize much of the gain. Likewise one might argue that "winning" is more analogous to sustained market leadership for years after an IPO. We agree, but we feel that for the early-stage investors, the IPO is a landmark that more directly corresponds to their "payoff." Acquisition is a distant second in terms of payoff (Gompers & Lerner, 1999).

VCs may not know the number of players in advance. In addition, they may take into consideration how the odds of success might be affected by not only their financial investment, but their managerial and industrial sector expertise. However, these complications do not necessarily change the optimal bid. To complete the analogy, in several industries, the amount "won" by the winning investor is approximately equal to the amount invested by all the rest.

Attractiveness of the Calcutta Auction

One can ask, "why would anyone want to participate in such an auction?" We postulate that the Calcutta auction is more efficient: it is a market-based system for pricing information asymmetries in markets where the number of people examining the market is small. In a typical traditional professional football pool, bookies change their odds as people bet, but this requires in depth knowledge of the teams and many people betting. In contrast, it would be very difficult for an odds-maker to make a market in less publicized tournaments, such as a backgammon or amateur golf tournament, where information on different players is less widely known.

In addition, from the bidders' point of view, bidders might feel that they have an informational advantage (knowledge of the players) that they hope to exploit. That is, the bidder might have an a priori probability that a certain player might win and may hope to bid for the player at a price lower than what would be indicated by his chance of winning. In the VC world, this suggests that the bidders (the VCs) think that they may be able to influence the chances of the chosen player's victory.

THE MODEL

Analysis of the Calcutta auction mechanism

Assume that n players participate in a tournament. For simplicity assume also that only one player can win this tournament. Prior to the start of the tournament the n players are auctioned off, typically in a sequential manner. Label the players as one through n. Assume that they are auctioned off in the same sequence. A bidder can bid on any number of players. The auctions are of the English type, and we assume that in each auction the winning bidder pays the bid amount. Denote the winning bid for player i or equivalently the dollar amount paid for player i as x_i.

Assume that (according to the rules of the auction) there is a unique winner in each auction for a player, thus the same player can not be "won" by more than one bidder. Moreover, a bidder cannot win in more than one auction. Thus, the number of bidders is assumed to be strictly greater than n. The bid amounts are pooled and the total is sometimes simply called the Calcutta pool. In our notation, the Calcutta pool amount is given by: $X = x_1+x_2+...+x_n$. We assume that there is a fixed fee as well as a variable administrative fee charged for running the auction. Thus we describe the administrative fee as: $a + bX$, where a and b are pre-specified real numbers.

The tournament begins after all players have been auctioned. The tournament could be an event in a bridge tournament, a backgammon tournament, a golf match, a fishing tourney, etc. If player i wins the tournament then the bidder who won the auction for player i, say, B_i, is awarded the amount: $X – (a + bX)$.

To keep the analysis simple, assume that player i is likely to win the tournament with probability p_i and that this probability does not depend on the bid amounts or the size of the pool. The bidders are aware of and agreed upon these probabilities. Assume that the amounts bid until the beginning of the auction for player *i* are known to all the bidders. All bidders are expected value maximizers and they do not collude with one another.

Given the sequence described above, We now address the following questions. What should be the optimal bid amount for player *i*? Which parameters of the auction determine the size of the Calcutta pool? What happens if the sequence of players auctioned is different? Is the knowledge of the number of players essential? Is the sequential auction format essential? What happens if the number of players is random? What is the impact of an auction for some player, say $i < n$, that ends with the bid amount less than or greater than the optimal bid amount? In order to relate the auction outcome to VC investment, we also ask whether and how the outcome is affected if there is a non-zero probability known to every player that the pool will not be distributed?

To facilitate the analysis, denote $X_i = x_1 + x_2 + ... + x_i$. In words, X_i is the total of the amounts bid for players one through *i*.

Proposition 1: The optimal bid for player *i* is given by

$$x_i = \frac{p_i}{\left(1-(1-b)\left(p_i + p_{i+1} + ... + p_n\right)\right)}\left((1-b)X_{i-1} - a\right). \qquad (1)$$

Proof: The auction can be modeled as a game of complete and perfect information. Thus, the optimal bid amounts can be computed by backwards induction. Consider the last auction prior to the beginning of the tournament. The bidders are aware that the amount so far collected equals X_{n-1}. Thus, the bid amount for the *n*-th player should just equal the expected value of winning the pool. After the auction the Calcutta pool equals $(X_{n-1} + x_n)$. The payout is not equal to this amount but an amount adjusted for the administrative fees and is given by:

$$\left(X_{n-1} + x_n - a - b\left(X_{n-1} + x_n\right)\right).$$

The successful bidder in the n-th auction wins the pool if the n-th player wins the tournament, an event that has probability equal to p_n. Thus, we require

$$x_n = p_n\left(X_{n-1} + x_n - a - b\left(X_{n-1} + x_n\right)\right)$$

or $$x_n = \frac{p_n}{\left(1-(1-b)p_n\right)}\left((1-b)X_{n-1} - a\right).$$

Now assume that the optimal bid amount is given by equation (1) for $i = j+1, j+2, \ldots, n$. Moreover, for the same values of i, assume that the total of the optimal amounts bid for players i through n is given by

$$x_i + x_{i+1} + \ldots + x_n = \frac{\left(p_i + p_{i+1} + \ldots + p_n\right)}{\left(1-(1-b)\left(p_i + p_{i+1} + \ldots + p_n\right)\right)}\left((1-b)X_{i-1} - a\right). \qquad (2)$$

Thus, there are now two backward induction assumptions. We have established these to be true for $i = n$. Consider the j-th auction. The amount in the pool at the beginning of this auction is X_{j-1}. As before, we equate the bid amount x_j with the expected value of the payout from the pool. From (2), if the winning bid is x_j then the Calcutta pool is given by

$$X = X_{j-1} + x_j + \frac{\left(p_{j+1} + \ldots + p_n\right)}{\left(1-(1-b)\left(p_{j+1} + \ldots + p_n\right)\right)}\left((1-b)(X_{j-1} + x_j) - a\right).$$

Thus, we should expect

$$x_j = p_j\left((1-b)\left(X_{j-1} + x_j + \frac{\left(p_{j+1} + \ldots + p_n\right)}{\left(1-(1-b)\left(p_{j+1} + \ldots + p_n\right)\right)}\left((1-b)(X_{j-1} + x_j) - a\right)\right) - a\right)$$

or $$\Leftrightarrow \quad x_j = \frac{p_j}{\left(1-(1-b)\left(p_j + p_{j+1} + \ldots + p_n\right)\right)}\left((1-b)X_{j-1} - a\right).$$

Therefore, (1) holds for the j-th auction. Using this expression for x_j and plugging it into (2) for $(j+1)$, leads to:

$$\sum_{i=j}^{n} x_i = \frac{p_j}{\left(1-(1-b)\left(p_j + p_{j+1} + \ldots + p_n\right)\right)}\left((1-b)X_{j-1} - a\right) + \sum_{i=j+1}^{n} x_i$$

$$= \left(\frac{p_j}{\left(1-(1-b)\left(p_j + p_{j+1} + \ldots + p_n\right)\right)}\right)\left((1-b)X_{j-1} - a\right) + \frac{\left(p_{j+1} + \ldots + p_n\right)}{\left(1-(1-b)\left(p_j + p_{j+1} + \ldots + p_n\right)\right)}\left((1-b)X_{j-1} - a\right)$$

Or, $$x_j + x_{j+1} + \ldots + x_n = \frac{\left(p_j + p_{j+1} + \ldots + p_n\right)}{\left(1-(1-b)\left(p_j + p_{j+1} + \ldots + p_n\right)\right)}\left((1-b)X_{j-1} - a\right).$$

Thus, (2) holds for the j-th auction. This completes the proof of the induction step. _

Proposition 2: The optimal bid for player *i* is unaffected by the sequence in which players are auctioned off.

Proof: Due to (1) and (2) it follows that an interchange in the sequence for players *i* and (*i+1*) does not affect the optimal bids for the remaining players. We show that such an interchange does not affect the bids for these two players as well. Let:

$$x_i = \frac{p_i}{\left(1-(1-b)\left(p_i + p_{i+1} + \ldots + p_n\right)\right)}\left((1-b)X_{i-1} - a\right)$$

$$y_i = \frac{p_i}{\left(1-(1-b)\left(p_i + p_{i+2} + \ldots + p_n\right)\right)}\left((1-b)(X_{i-1} + y_{i+1}) - a\right)$$

$$x_{i+1} = \frac{p_{i+1}}{\left(1-(1-b)\left(p_{i+1} + \ldots + p_n\right)\right)}\left((1-b)(X_{i-1} + x_i) - a\right)$$

$$y_{i+1} = \frac{p_{i+1}}{\left(1-(1-b)\left(p_i + p_{i+1} + \ldots + p_n\right)\right)}\left((1-b)X_{i-1} - a\right).$$

That is, y_i and y_{i+1} stand for the optimal bids with the sequence of bidding interchanged. We have to show that $x_i = y_i$ and $x_{i+1} = y_{i+1}$. We can re-express,

$$x_i - y_i = K\begin{pmatrix}\left((1-b)X_{i-1} - a\right)\left(1-(1-b)\left(p_i + p_{i+2} + \ldots + p_n\right)\right) \\ -\left((1-b)(X_{i-1} + y_{i+1}) - a\right)\left(1-(1-b)\left(p_i + p_{i+1} + \ldots + p_n\right)\right)\end{pmatrix}$$

$$= K(1-b)\Big(\big((1-b)X_{i-1} - a\big)p_{i+1} - y_{i+1}\big(1-(1-b)(p_i + p_{i+1} + \ldots + p_n)\big)\Big),$$

where K does not involve the optimal bid quantities. Thus, x_i equals y_i if and only if $x_{i+1} = y_{i+1}$.

But,

$$x_{i+1} - y_{i+1} = K_1\left(\begin{array}{l}\big((1-b)(X_{i-1} + x_i) - a\big)\big(1-(1-b)(p_i + p_{i+1} + \ldots + p_n)\big) \\ -\big((1-b)X_{i-1} - a\big)\big(1-(1-b)(p_{i+1} + \ldots + p_n)\big)\end{array}\right)$$

$$= K_1(1-b)\Big(\big((1-b)X_{i-1} - a\big)p_i - x_i\big(1-(1-b)(p_i + p_{i+1} + \ldots + p_n)\big)\Big) = 0,$$

where K_1 does not involve the optimal bid quantities and the last equality follows from (1). _

This result leads to a somewhat surprising proposition.

Proposition 3: The key parameters that decide the value of the Calcutta pool are a and b. In fact, the value of the pool is given by: $X = -(a/b)$.[4]

Proof: From Proposition 2, we know that the sequence of the auction does not matter. Thus, we shall examine the cases that the first player is auctioned either first or last. In the former case, from (1) (and defining $X_0 = 0$)

$$x_1 = \frac{p_1}{\big(1-(1-b)(p_1 + p_2 + \ldots + p_n)\big)}(-a).$$

In the latter case, (by equating expected value of the payoff with the optimal bid amount)

$$x_1 = p_1\big((1-b)X - a\big).$$

Thus, equating the two expressions for x_1, we get the size of the Calcutta pool to be

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[4] In the originally envisioned Calcutta auction (see appendix), 100 tickets were sold for 10 rupees each, thus creating a pool of 1000 rupees. Then tickets were drawn and matched against horses. The lucky holders of these tickets could then turn around and auction them off to the highest bidder before the race took place. Over the years, the initial pool concept has disappeared.

$$\frac{p_1}{\left(1-(1-b)\left(p_1+p_2+...+p_n\right)\right)}\left(-a\right)=p_1\left((1-b)X-a\right)$$

$$\Leftrightarrow X=-\frac{a}{(1-b)}\frac{(1-b)\left(p_1+p_2+...+p_n\right)}{\left(1-(1-b)\left(p_1+p_2+...+p_n\right)\right)}=-\frac{a}{b}.$$ _

Seeding the pool

We term this result as “seeding the pool.” The value of the pool is non-negative if the value of *a* is negative and the value of *b* is less than one. Thus, the promoter of the auction needs to entice the bidders with some initial pool amount. (Note that the promoter recovers the seed amount via the variable administrative fee, namely, $b\times X=b\times\frac{-a}{b}=-a$.) The fact that the organizers do not need to seed the pool in Calcutta auctions now-a-days is surprising. However, the excitement generated by the bidding as well as the interest in witnessing the tournament might explain why *a* is never negative in a real-world Calcutta auction. Of course, another explanation for why in reality pools do not need to be seeded might be that the estimates of the probability of winning add up to a quantity greater than one, i.e., bidders exhibit overconfidence. (If $\left(p_1+p_2+...+p_n\right)$ exceeds one then the numerator in the second last expression in the last proof can become negative.) A third possibility for explaining why the pool does not have to be seeded in real-world Calcutta auctions is that the "winner’s curse" (Thaler, 1988) might operate in overtime here if in each auction the winning bidder gets the winner's curse. Assume from this point forward that *a* is negative.

Proposition 4: The sequential bidding format is not necessary. The optimal bid in the auction for the *i*-th player is $x_i=-\frac{p_i a}{b}$ given bidders follows the same strategy in other auctions.

Proof: Follows from propositions 2 and 3 above. _

Proposition 5: There is never a need to know the total number of players.

Proof: Follows from proposition 4 as the optimal bid amount for any player depends only on the values of *a* and *b*. _

Finally, we approach the last two questions we posed.

Proposition 6: If the probability that the money in the pool is distributed according to the rules of the game is p_d (in other words the sponsors of the auction go bankrupt in the meanwhile with probability $1- p_d$), then the optimal bid for player *i* is $x_i = -p_d \frac{p_i a}{b}$.

We can argue that if some player makes an error, say ε, in the sequential format of the auction and if the expected value of this error is zero then the net effect is for subsequent bidders to revise their bids by an amount equal to the value of the error divided by the probability of the player winning the tournament. In other words, errors affect subsequent bids, and in the same manner as the fixed fee *a*.

In summary, the three important conclusions are in Propositions 3, 4, and 6. We now apply them to new markets. The seeding of the pool (–*a*) is equivalent to the value of early entry into a new potential profit site, which refers to a unique market or market segment in which a firm may compete and presumably reap profits (Afuah and Tucci, 2003). Firms that wish to enter and compete in this market make investments, knowing that others will be making similar investments and that these investments work together to develop the market. The extent to which there are market development externalities determines the value of *b*. If everybody's investment worked together to develop the market, then the winner realizes the benefits of everybody else's efforts. The amount gained relative to the total investment would therefore be large, implying a low variable administrative fee, *b*. Thus if these market development externalities are small, then *b* is large; otherwise if these externalities are large, then *b* is small.

It is indeed surprising that it is the ratio of these two quantities (*a* and *b*) that determines investment behavior when there are market development externalities such as those that might be present during the development of new markets. We illustrate this in the next section.

Data

In this section, we illustrate several aspects of the model with archival data. The data are drawn from the VentureSource database, which contains information about most venture capital investments in companies during the last ten years. With more than 9,200 venture-backed companies, 26,000 financing transactions and 61,000 key executives in the US venture capital industry, the database is considered one of the most comprehensive in the industry. We randomly selected ten industries within the "Internet Focus" section of the database. These ten industries have a wide range of total investment, average investment, entry timing, and IPO outcomes. The industries are (1) telecommunications , (2) broad retailing, (3) books, (4) jewelry, (5) investment banking, (6) wireless, (7) pet supplies, (8) food, and (10) job placement services. Each industry has 5 to 10 startup companies in it, with an average of 8.1 companies.

We documented every stage, amount, and date of investment for the companies up to and including an IPO, if applicable. Thus we know the total VC investments in the industry and who made them. If a company eventually went public, we obtained from the SEC filings who owned it and matched the names of the earlier stage investors with those shareholders. We were thus able to compute a "payoff" to early stage investors by multiplying the value of the company at their IPO by the beneficial ownership of the company. While venture capitalists may not be able to sell at the IPO and thus the calculation might overstate their actual payoff, the VCs may be able to hedge against changes in the stock price post-IPO and thus realize most of their interest in the company. Furthermore, we assume that if the company does not go public, the payoff to the VCs on average is minimal (Gompers & Lerner 1999).

We set the stage for the analysis of the Calcutta auction by displaying varying estimates produced by a traditional method of valuing firms. As explained in the introduction, one way of examining this is to look at VC investment in an industry and calculate how much an increase in sales in the industry would be expected to justify those investments (see Table 1). Notice the huge variation in sales growth expected across industries. When looking at this table one must ask whether information gleaned from any one subsector in electronic markets could possibly be useful in understanding any other subsector.

***** Insert Table 1 about here *****

Our analysis of these investments is based on the predictions of the Calcutta auction model. If the auction model describes the investment phenomenon, we expect to verify at least the prediction of Proposition 3. We estimate the values of the fixed administrative fee a, and the size of the total investments (Calcutta pool) X. It seems logical that the Calcutta pool in any given industry can be set equal to the total venture investment in that industry. The estimate of a, or how the pool is seeded, might be done in several ways. For example, we could use (1) the first "spike" of investments in that industry as a proxy for the initial worth of the market, (2) the amount raised by a firm in the first IPO in that industry, (3) the total market value of the first IPO, or (4) the total market value of all IPOs in that industry.

We computed the "first spike" by graphing the value of the investments in ten industries and looking for an investment large relative to the prior investments. All industries had some small investments in the early stages and it was relatively easy to spot the first large investment (see for example Figure 1). Table 2 shows our estimates of *a* for each of these four methods. We evaluate these methods below.

***** Insert Figure 1 and Table 2 about here *****

The values for the variable administrative fee *b* can now be computed as the ratio of the size of the pool divided the fixed administrative fee (see Table 2). The "first spike" method of estimating *a* produces estimates of *b* in the range of 0.06 to 0.56 with an average of 0.19. That is, on average, the winning firm expected to realize 81% of all investment in the industry from its IPO. If we assume that seeding of the pool was accomplished by the amount raised in the first IPO, we find that *b* ranges in the interval [0.07, 0.70] with an average of 0.29. For seeding based on all IPOs' market cap, we find *b* in the range [0.11, 3.05] with an average of 1.35 (!), while for seeding based on the market cap of the first IPO, we find *b* in the range of [0.11, 1.84] and an average of 0.79. The standard deviation tracks exactly the average (i.e., standard deviation of *b* using the first spike method is the lowest [0.15] and using the all-IPO market cap method is the highest [1.06]). Recall that if the variable administrative fee is very small, the total investment is roughly the same as the payoff to winning investors. However, if the administrative fee is very large, the payoff to investors is much smaller than the total amount invested in the industry. Note that when *b* is greater than 1.0, it signifies that the firm realized less than the seeding of the pool. Two out of the four ways of estimating *a* appear to produce values of *b* that are inconsistent with the model. This is not surprising as the latter two methods of estimating *a* refer to value of all firms accumulated over a long period of time and do not provide a good indication of "seeding of the pool," which occurs at the beginning of the "tournament."

DISCUSSION

In this paper we propose a framework for analyzing seemingly non-rational investment behavior. The variety of examples we provided show that investments in Internet type businesses cannot be explained by traditional valuation models, which assume that the amount of investment is closely related to the expected cash flow. The numbers in our examples imply expected industry growth in excess of what would be predicted by any traditional valuation model. In examining this paradox we reviewed a variety of explanations that assume that investor behavior is not perfectly rational. In contrast, ideas such as herding and market myopia were proposed to account for such behavior.

We approach the problem in a different way. We model the VC investing as a Calcutta auction and propose that this mechanism can predict the amounts invested we observe. The Calcutta auction appears to be a good mechanism to explain behavior in markets that are characterized by uncertainty, information asymmetries and by small number of participants. Under these conditions behavior that departs from what would be typically prescribed by a "rational" model is more likely to be observed. However, the Calcutta auction mechanism is shown in this paper to provide a good explanation of the actual bids put up by VCs. Indeed, several bids that are characterized as departing from rationality according to traditional valuation models can be described more naturally by the Calcutta auction model.

Most of the models that were proposed to explain the "abnormal" investment in Internet industries included some element of irrationality. Such were the models that explained technology races and those that assumed herd behavior or investors' irrational exuberance. Our approach suggests that in considering investment under such conditions of high uncertainty, the behavior of investors can be explained without resorting to arguments about irrationality albeit including some behavioral components.

For instance, in the absence of past data on investment in such industries what value would one take as an indicator of the potential value of such investment? An investor can ask what is the correct signal: Is it the market value of the firm or the first spike of money raised by the VCs? These two signals provide information to subsequent investors. The fact that a firm goes to an IPO can be considered as analogous to a "victory" in the market. However, it may not be accurate to equate market valuation based on an IPO with the seeding of the pool. We can distinguish between two signals coming out of the first IPO. The first is the total market capitalization of the firm immediately following the IPO. As mentioned above, the IPO indicates the "victory" of the VCs who put the money in the particular company earlier. However, the total market cap may be an inflated estimate of the pool of money available. In contrast, the cash amount raised in the first IPO is a more natural measure of the seeding of the pool. It is also more natural in that it represents the investment by early investors and thus provides a measure of that part of a firm's value that accrues to early investors. The VC's are probably more interested in this cash amount than in the total value of the firm. The first spike of VC investment provides a similar signal.

In estimating the values of a and b we note that in some cases, as shown in Table 2, the value of b is higher than one. This occurs when we use the market value of the firm after IPOs (either the first one or the total of all of them) as an estimate for the seeding of the pool. On the other hand, both the first spike and the cash raised in the first IPO lead to sensible values of the administrative fee, b. For the case of the first spike, the values of b are also close together (mean of 0.19 and standard deviation of 0.15). The relatively low values of b for either of the first two methods indicate that the Calcutta auction accurately describes the behavior – a winner take all phenomenon, probably fueled by the externalities in market development efforts. Notice that the claim is not that individual investments affect the probability of success of a given firm but that they increase the conditional expectation of return when that firm is successful. In other words, when more firms enter everybody knows that the probability of winning is lower but the stakes are higher hence the conditional expectation upon winning is higher. Large values of *b* indicate that the return to a firm is not affected by the efforts of other firms, whereas small values of *b* imply spillover effects from one firm to another.

One can argue that an indicator such as the first spike may be unreliable or biased. Yet, behavioral studies suggest that in forecasting under uncertainty people often use heuristics rather than normative rules such as Bayes theorem. One of these heuristics, called anchoring and adjustment (Tversky and Kahneman, 1974), suggests that in making predictions under uncertainty people cling to an anchor that is provided to them and then they do no adjust enough (in comparison to Bayes rule) when new information arrives. Thus, the first spike may provide VCs with an anchor according to which they decide on their investment without adjusting it enough when new information becomes available.

Other heuristics that may play a role in affecting VCs decisions whether to invest in such industries are the availability and representativeness heuristics (Tversky and Kahneman, 1974). According to the former, when making a probabilistic judgment people often rely on information that is readily available and salient. For instance, after a plane crash people tend to overestimate the probability of airline accidents. According to the representativeness heuristic, people perceive certain events as a reliable source if they appear to be representative of the population of events that they are looking at to make a probabilistic estimate. Thus, in many cases people would base their estimates on a small (and unstable) sample for making such a forecast if it appears to be representative of the population upon which they make inferences. If the sample appears to be representative they may correct their estimates accordingly. For instance, many people expect a fair coin flipped randomly to alternate between heads and tails even in a small sample of coin flips. This phenomenon has long been known in statistical inference as the "gambler's fallacy." The use of these heuristics has often been interpreted as a demonstration of the fallibility of judgment; yet, as Hogarth (1981) noted, they sometime serve a function with respect to the effort people put into processing information. It is plausible that in the context we are examining such heuristics may affect the way VCs make their judgments and subsequent decisions.

Given that in many auction type situations people behave in a way that can be considered as irrational such as in the case of the winner's curse (Thaler, 1990), one can ask if the behavior in the context of the Calcutta auction is irrational. In discussing this issue, we bring two aspects of the decisions: First, is the particular investment considered an overpayment or an underpayment. Second, is the value of the variable administrative fee, *b*, small or large.. We consider the two aspects jointly.

It can be argued that an investment that deviates significantly from the "true" value of the firm is not rational. Clearly an overpayment is irrational, while an underpayment may provide the winner with a short-term position that cannot be easily defended. Gompers and Lerner (1999) propose that there is a 20% chance of a typical VC-funded venture going to an IPO. If we look at the total number of firms that went public divided by the total number of firms across our ten industries, we see that 19 out of 81, or 23% of, firms went to IPO. By this measure, we expect to see the average investment in each industry to be approximately equal to 20% of the total investment in that industry. Any deviation from this norm could be termed a "violation of rational valuation" based on Propositions 4 and 5. The violation can be either large or small with respect to more traditional valuation methods, for example, the first method of valuation discussed in this paper. This alone does not allow us to conclude whether an investment is rational or irrational. We have to factor in whether the administrative fee *b* is large or small. The value *b* depicts the difference between the total investment in the industry (by all investors) minus the amount claimed by the winner, divided by the total investment

The administrative fee *b* could be either large with respect to the mean (i.e., 0.20) or small with respect to the mean (less than 0.20). Recall that if *b* is large then the spillover effect of one firm's investment on the size of another firm's return when successful is small. Therefore, if *b* is large and the violation with respect to traditional methods is small, we classify the investments as "rational." We can similarly conclude that the investments are rational if *b* is small and the violation with respect to traditional valuation methods is large. On the other hand, if *b* is large and the VC's valuation of their firms grossly exceed the values computed using more traditional methods, then we classify that as exuberant investing. In other words, if valuations were unusually high, that in and of itself does not mean irrationality is at play. But if valuations are unusually high and the payoff to investors was unusually low based on our measure of the administrative fee *b*, then we can say that the investments seem irrationally exuberant. Likewise, if *b* is small and the violation with respect to traditional measures of valuation is small, then we might classify the investments as irrationally pessimistic. Putting this all together, we propose the framework shown in Figure 2, which includes also examples of industries.

***** Insert Figure 2 about here *****

It appears that the VC investment behavior in the electronic markets we examined was not necessarily "irrational." Those VCs were aiming to "win" the cash invested in the market and were apparently not as concerned with what happened thereafter. Thus, the Calcutta auction is a good model for the "winner take all" pattern of behavior even though such behavior may be at odds with social welfare and irrational from a macroeconomic perspective.

CONCLUSIONS

In this paper, we make three main contributions. The first is the notion that externalities of market development efforts affect firm valuation in electronic markets. The second is that you can have irrationality with small investments and rationality with large investments in newly discovered markets. Small investments are irrational when there are significant market development externalities. Large investments are irrational when such externalities are absent. The third is that analogous to the Calcutta auction, the total VC investment in an industry seems to depend on two factors, the initial “value” of the undeveloped market called the seeding of the pool as well as the fraction of individual VC investment that works to develop the market for other entrants. Individual VCs need to estimate, in addition, their probability of success of winning the competition, that is, their probability of going to IPO first. The key aspect in these estimates is being able to guess the initial worth of the undeveloped market or the seed amount. As new markets are discovered, the investors obtain a (possibly noisy) signal about the initial worth of the market. Based on the data, the signal in electronic markets is either the first "spike" of VC investment or the cash raised in the first IPO. We have used the Calcutta auction to analyze the investment behavior of VCs in electronic markets. The analysis threw new light on previously held conceptions on the rationality of investment in these industries. Future research should examine the applicability of the Calcutta auction to explain investment phenomenon in other newly discovered markets.

REFERENCES

Afuah,A, and C. L. Tucci. 2003. *Internet Business Models and Strategies*, 2nd Edition. New York: McGraw-Hill.

CNN. "Venture capital dips again." November 1, 2001. <http://money.cnn.com/2001/11/01/smbusiness/venture/>

Devenow, A. and I. Welch. 1996. Rational herding in financial economics. *European Economic Review*. 40:603-615.

P. A. Gompers and J. Lerner. 1999. *The Venture Capital Cycle*. The MIT Press, Cambridge, MA.

Hobbs, H. The Romance of the Calcutta Sweep. 1930. Calcutta: Thacker's Press & Directories.

Hogarth, R. 1981. "Beyond discrete biases: Functional and dysfunctional aspects of judgmental heuristics." *Psychological Bulletin*, 90, 187-217.

Jensen, Michael, C. “Agency Costs of Free Cash Flow, Corporate Finance, and Takeovers,” The American Economic Review, May 1986, 76, No. 2, pp. 323-329.

Lerner, Josh. 1997. An empirical examination of a technology race. *Rand Journal of Economics*. 25: 319-333.

Pearson, R. 1954. Eastern Interlude. Calcutta: Thacker, Spink, & Co.

Perkins, E. B. 1950. Gambling in English Life. London: Epworth.

Salhman, W. A. and H. Stevenson. 1986. Capital Market Myopia. Journal of Business Venturing 1:7-30.

Surita, P.H.R. 2002. The Parades gone by : 150 years of Royal Calcutta Turf Club. Calcutta: Royal Calcutta Turf Club.

Thaler, R. H., *The Winner’s Curse*. New York: Free Press, 1992.

Tversky, A. and Kahneman, D. 1974. "Judgment under uncertainty: Heuristics and biases". *Science*, 185, 1124-1131.

US Bureau of the Census. 2000. <http://www.census.gov/csd/ace/view/ace99.html>.

US Department of Defense. 2000. <http://www.defenselink.mil/pubs/allied_contrib2000/E-1.html>.

Webster's Unabridged Dictionary of the English Language. 2000.

Industry	VC Internet investment, 1999	Sales to capital ratio, 1999	Total Industry Sales, 1999	Incremental sales expected	Estimated new sales	Percentage increase
Pet supply	352	30	1550	10560	12110	681
Biotech/ pharmaceuticals	179	28	183021	5012	188033	2.74
Books	194	24	24136	4656	28792	19.3
Broad retail	257	38	8387	9766	18153	116
E-software	193	30	3487	5790	9277	166
Food + Garden	682	48	48273	32736	81009	68
Sporting goods	29	39	335	1131	1466	338
Telecoms	818	4.5	795340	3681	799021	0.49
Vehicle parts	1.5	33	8619	49.5	8668.5	0.57
Wireless	106	23	96249	2438	98687	2.53

Table 1. Incremental sales necessary to justify investment in ten industries ($ millions except sales-to-capital and percentage increase)

			first spike		Amount raised in first IPO		Market cap of all IPOs		Market cap of first IPO	
Industry	No. of firms	Total investment ($ million)	–a	b	–a	b	–a	b	–a	b
Wireless	10	171.3	96	0.56	96	0.56	202	1.18	202	1.18
Telecommunications	10	975	62	0.06	108.8	0.11	893	0.92	397	0.41
Pet Supplies	10	488	130	0.27	130	0.27	165	0.34	165	0.34
Garden Supplies	5	70.5	20	0.28	49.2	0.70	130	1.84	130	1.84
Food	10	1036	120	0.12	64	0.06	2998	2.89	870	0.84
Broad Retailing	6	343.8	25	0.07	129.6	0.38	36.4	0.11	36.4	0.11
Books	7	355.6	54	0.15	54	0.15	739	2.08	217	0.61
Jewelry	7	287	30	0.10	81.25	0.28	171	0.60	171	0.60
Investment Banking	7	336	28	0.08	68.4	0.20	1025	3.05	513	1.53
Job Placement	9	242.1	58	0.24	58.5	0.24	113	0.47	113	0.47
Average				0.19		0.30		1.35		0.79
Standard deviation				0.15		0.20		1.06		0.56

Table 2: Estimates of *a* and *b* in ten different industries

Figure 1. Total VC Investment in pet supplies over time

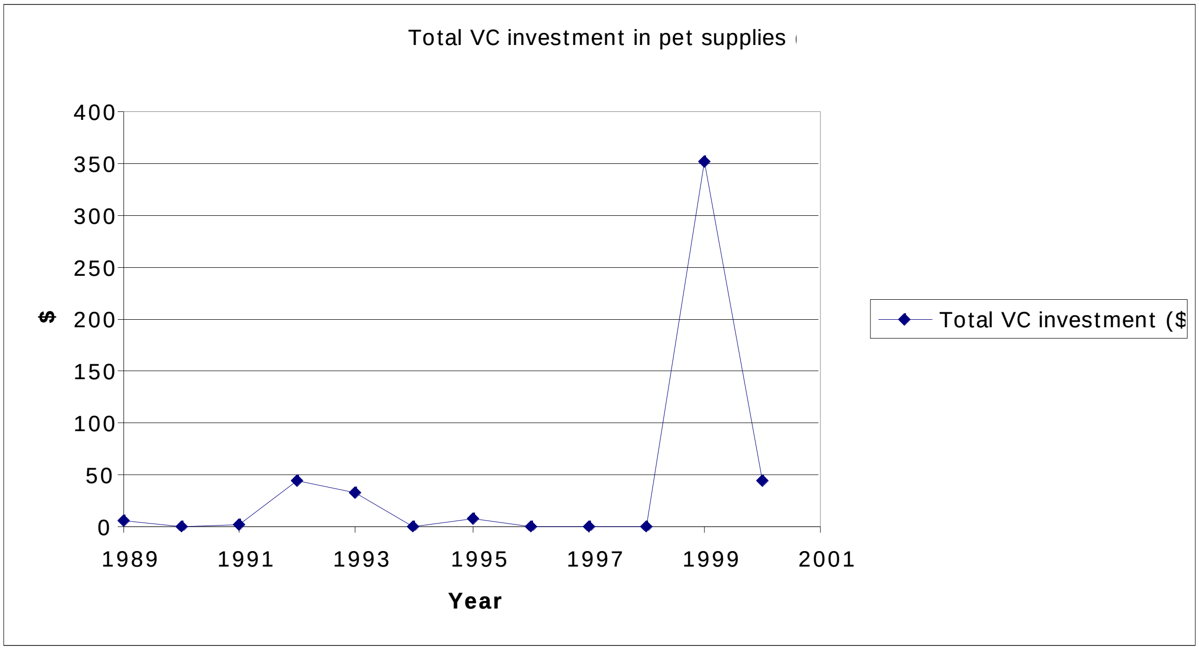
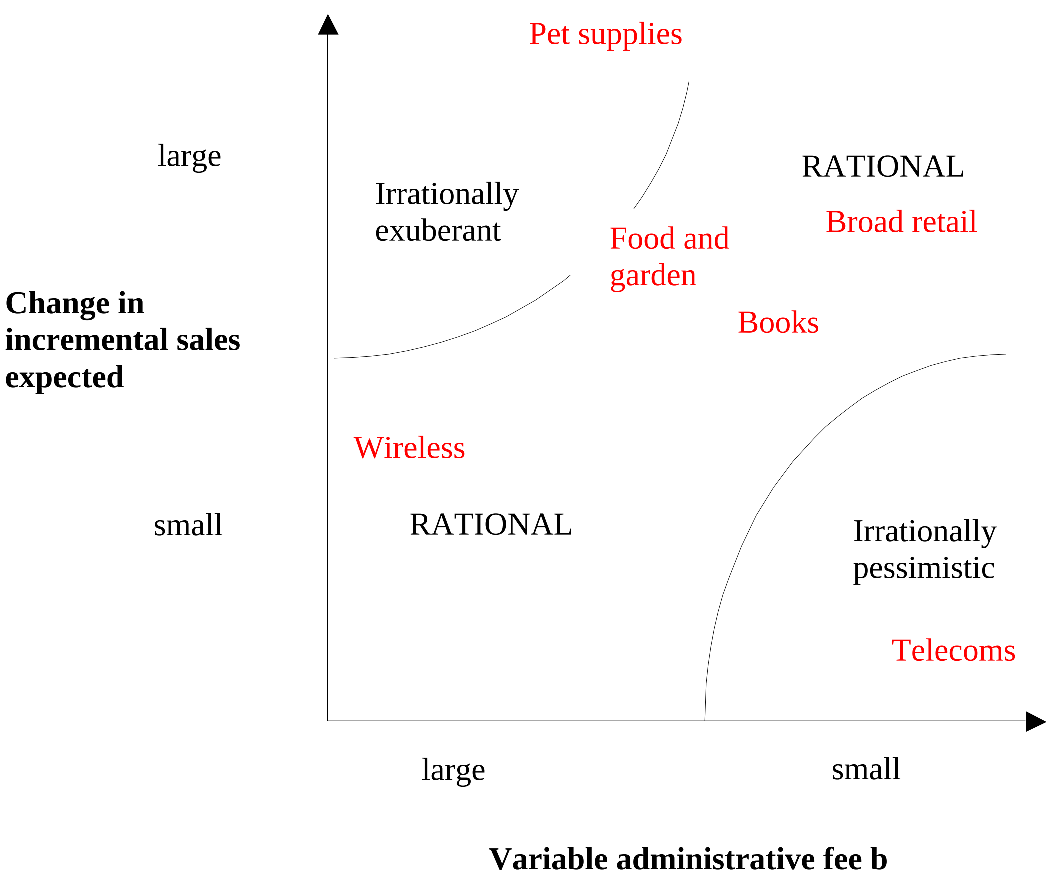


Figure 2. Rationality and VC investments according to the Calcutta auction model



Appendix 1. History of the Calcutta auction[5]

In the early 1800s when horse racing was introduced in Calcutta an auction form came to be used for betting on the outcome in the following way. Tickets were sold to the public for ten rupees each. Typically, there were 100 tickets, which was more than the number of horses in the race. After all the tickets were sold, a lottery was held for each horse in the race out of these 100 tickets. The ticket associated with the horse had an exclusive claim on the winnings for that horse. For example, after all 100 tickets were put into drum, the organizer would say, the next ticket we draw will be for "Valentine" for a race on February 1st, and that ticket would pay if Valentine won the race (or came in second or third as we will see below). Thus if there were fifteen horses in the race there would be 15 lucky winners. After the lottery, each of the fifteen tickets would be auctioned off to the highest bidder and the winning bid amounts were collected and pooled as described below. The winner of the ticket in these auctions would have exclusive rights to the winnings of that particular horse. Thus, favorites in the races would command higher auction prices than long-shots. The money collected was split between the original holder of the ticket and the pool. For example, if the ticket for Valentine on February 1st was auctioned for 100,000 rupees, then 50,000 would go to the lottery winner and the other 50,000 would be added to the original 1000 in the pool. The lottery winner would not have to auction off the ticket but could also hold onto it, or sell off only a partial share in the ticket (Hobbs 1930). This process would continue for all fifteen of the horses. When the race was over, the tickets paid the following: winner, 40% of the pool; second place, 20% of the pool, third place, 10% of the pool,

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[5] It is not surprising that such an auction format evolved opportunistically in Calcutta. For example, the East India Company sold its cargoes using the "public outcry" method early on, but soon a number of private firms sprang up in the Dharamtola-Lal Bazar area to liquidate the holdings of wealthy retiring merchants or those who died in Bengal without heirs (Pearson, 1954). Disease and natural disasters claimed the lives of many in the city every year, swelling the number of goods available at auction and increasing the scale of the auction area. Soon it was well known that almost any type of good — new or used — could be purchased at a "Calcutta auction."

and unplaced (divided equally among unplaced horses), 20% of the pool. The organizer kept 10% for its own use and for expenses related to the process.

Eventually, it seems as if an inability to pay the auction bids by bidders led to the formation of an official club in 1847, the Calcutta Turf Club, which regulated all aspects of the lottery, subsequent auction, and the race itself (Surita, 2002). The lottery was only open to members of the club (who could also act as agents and purchase tickets for others). In its heyday of the late 1920s, the pool reached levels of the equivalent of one million British pounds. After 1930 the popularity of the Calcutta auction diminished due to the introduction of pari-mutuel betting.

The Calcutta auction contrasts with traditional horse racing where anyone who bids on a winning horse has a claim on that horse's winnings. Perkins (1950) claims that the outcomes of some of these Calcutta auctions could make the winners wealthy — and by the way, perhaps ruin their lives much as we suspect these days that winning the lottery might do.

From there it seems natural that the auction technique could be extended to those participating in tournaments or sporting events.

A search on Google for the phrase “Calcutta Auction” resulted in over 250 hits. The summary of the first 12 pages of hits is as follows (name of sport or type of page followed by the number of hits — total hits are 67): Backgammon (18), golf (9), game fishing (7), boat racing (6), blackjack/poker (4), horse racing/jumping etc (4), horse show (3), tennis (3), dog racing (2), squash (2), gaming laws etc (2), and one each to bridge, car racing, cattle show, miniature horse show, pigeon racing, snow machine racing. As for geographic representation, results came from the following countries: Australia, Canada, The Netherlands, New Zealand, and the US. For example, a form from New Zealand elaborately sets out the information needed prior to granting a "Licence to Conduct a Calcutta."

Regarding the law, the Attorney General of Idaho responds to an inquiry and states: "In conclusion, it is the opinion of this office that calcutta wagering on events such as golf tournaments is not a permitted exception to Idaho's public policy prohibiting gambling as articulated in art. 3, § 20 of the Idaho Constitution and is prohibited by Idaho Code § 18-3801. Further, betting at a calcutta auction is criminally punishable as a misdemeanor pursuant to Idaho Code § 18-3802." September 17, 1993. It is fascinating to note that the same opinion states: "Germane to our analysis is art. 3, § 20(1)(b), which does permit a form of "betting" as opposed to a particular gaming activity. It is important to note that pari-mutuel betting is distinguishable from calcutta wagering or auction pools. Pari-mutuel betting allows patrons to select a contestant and place a wager upon that contestant, generally a horse or dog. Rather than one patron bidding against the other for the right to wager on a particular contestant, every patron is allowed to wager on the contestant of choice. The money wagered is pooled and odds are computed based upon the amount of money wagered on one contestant in relation to the other contestants in the race. The odds then determine how much money is paid to successful patrons. See Oneida County Fair Board v. Smiley, 86 Idaho 341, 386 P.2d 374 (1963)."