

Money Management

Martin Sewell

Department of Computer Science
University College London

May 2007, updated July 2008

1 Introduction

For a speculative investor, there are two aspects to optimizing a trading strategy. The first and most important goal of a trader is to achieve a positive expected risk-adjusted return. Once this has been achieved, the trader needs to know what percentage of his capital to risk on each trade. The underlying principals of money management apply to both gambling and trading, and were originally developed for the former.

2 History of Money Management

- In a paper on the measurement of risk that launched ‘expected utility theory’, Bernoulli (1738) proposed that people have a logarithmic utility function. He noted that, as a consequence of this, when profits are reinvested, in order to measure the value of risky propositions one should calculate the geometric mean. The paper was later translated into English (Bernoulli 1954).
- In an article on ‘Speculation and the carryover’ that focuses on cotton trading, Williams (1936) states that a speculator should bet on a representative future price, and points out that if his profits and losses are reinvested the method of calculating such a price is to choose the geometric mean of all the possible prices.
- In 1944 the mathematician John von Neumann and economist Oskar Morgenstern wrote *Theory of Games and Economic Behavior* (von Neumann and Morgenstern 1944). Now a classic book, this is the work upon which modern-day game theory is based.
- In 1948 Claud Shannon published an article entitled ‘A mathematical theory of communication’ in two parts (Shannon 1948). The paper established the discipline of *information theory* and became a classic. In short, he developed the concepts of information entropy and redundancy. Shannon

asserted that binary digits could be transmitted over a noisy channel with an arbitrary small probability of error if the binary digits were suitably encoded.

- In 1956 a scientist working for Bell Labs, John Larry Kelly, Jr., brought together game theory and information theory when he published ‘A new interpretation of information rate’¹ (Kelly 1956). He showed that in order to achieve maximum growth of wealth, at every bet a gambler should maximize the expected value of the *logarithm* of his capital, because it is the logarithm which is additive in repeated bets and to which the law of large numbers applies. The assumptions are that the gambler’s capital is infinitely divisible and all profits are reinvested. Money management systems which maximize the expected value of the capital are said to employ the *Kelly criterion*.
- Bellman and Kalaba (1957) considered the role of dynamic programming in statistical communication theory and generalized and extended (Kelly 1956)’s results.
- The first to introduce the Kelly criterion in an economic context, Latané (1959) showed that investors should maximize the geometric mean of their portfolios.
- Breiman (1961) proved that using the Kelly criterion is asymptotically optimal under two criteria: (1) minimal expected time to achieve a fixed level of resources and (2) maximal rate of increase of wealth. It is only in continuous time that the results are *exact*.
- In 1962, Edward O. Thorp, an American maths professor, author and blackjack player wrote *Beat the Dealer* (Thorp 1962), which became a classic and was the first book to prove mathematically that blackjack could be beaten by card counting.
- Thorp and Walden (1966) developed a winning strategy for a side bet in Nevada Baccarat and used the Kelly criterion to determine bet sizes.
- Thorp (1969) concluded that the Kelly criterion should replace the Markowitz criterion (Markowitz 1959) as the guide to portfolio selection.
- Hakansson (1970) consider the optimal investment and consumption strategies under risk for a class of utility functions and also give the necessary and sufficient conditions for long-run capital growth.
- Radner (1971) was the first to employ a balanced investment strategy in the context of stochastic generalizations of the von Neumann model of economic growth.

¹The original title was ‘Information theory and gambling’, but Kelly changed it to appease his employer.

- Thorp (1971) applied the Kelly criterion to portfolio choice.
- Samuelson (1971) showed that it is *not* the case that the geometric-mean strategy is optimal for any finite number of periods, however long, or that it becomes asymptotically a good approximation.
- Goldman (1974) showed that the policy of maximizing the expected logarithm of terminal wealth as applied to bounded utilities when the time horizon is long is not always optimal.
- Merton and Samuelson (1974) exposed the fallacy of the log-normal approximation to optimal portfolio decision-making over many periods.
- Miller (1975) showed that when the horizon is infinite, the investment policy of maximizing the expected log each period is optimal when the utility function depends only on the tail of the sequence representing the capital at each period.
- Kraus and Litzenberger (1975) developed a competitive equilibrium model of a market embodying heterogeneous beliefs. They assumed that each investor maximizes the expected logarithmic utility of his future wealth by selecting state-by-state claims to future wealth constrained only by his initial wealth.
- Friedman (1976) presented ‘Understanding and Applying the Kelly Criterion’ to the Third Conference on Gambling and Risk Taking in Las Vegas, Nevada in December 1976.
- Markowitz (1976) argued that in the sequence-of-games formalization of the maximum-expected-log rule the criterion for asymptotic optimality adopted by Merton and Samuelson (1974) and Goldman (1974) is unacceptable, because it violates the notion that only the normalized form of the game is necessary for comparing strategies.
- Economists take a dim view of the Kelly system, in a notable attack Samuelson (1979) wrote a journal article using words of one syllable only, ‘Why we should not make mean log of wealth big though years to act are long’ which was published in the normally polysyllabic *Journal of Banking & Finance*. His point was that ‘[w]hen you lose – and you *sure can* lose – with N large, you can lose real big.’
- Bell and Cover (1980) used a game-theoretic model of a market by implementing a one-shot, two-player, constant-sum game where the goal of each investor is to maximize the probability of outperforming the opponent. They found that a Kelly investor has at least a 50% chance of out-returning any other gambler after just one trial.
- Thorp (1980) published ‘The Kelly money management system’ in the *Gambling Times* which detailed the Kelly formula.

- Finkelstein and Whitley (1981) extended the results of Kelly and Breiman and showed that a Kelly investor is never behind any other gambler on average after any fixed number of bets.
- Wong (1981) showed that when using optimal proportional betting in blackjack, your expected win divided by your bet size is half of your expected arithmetic win rate.
- Gehm (1983) wrote *Commodity Market Money Management*, which includes Thorp's implementation of the Kelly criterion (Thorp 1980).
- Ethier and Tavaré (1983) showed that the ratio of your return on investment under optimal proportional betting to your return on investment under constant betting converges to an exponential distribution with mean $\frac{1}{2}$ as your advantage tends to 0.
- Griffin (1984) considered different measures of win rate for optimal proportional betting.
- In a book about betting on horse racing, Ziemba and Hausch (1985) showed that for lengthy sequences of bets a Kelly investor's expected capital growth much exceeds that from alternative investment strategies.
- Pestien and Sudderth (1985) demonstrated how to control a diffusion to a goal in continuous-time.
- Heath, *et al.* (1987) showed in continuous time that if one is managing a portfolio of stocks, bonds and cash and wishes to minimize the expected time to reach a given total worth, then the Kelly strategy is optimal.
- Ziemba (1987) simulated 1,000 seasons of betting on 700 horse races and demonstrated that proportional betting using the Kelly formula was superior to any other staking strategy.
- Algoet and Cover (1988) proved that maximizing conditionally expected log return given currently available information at each stage is asymptotically optimal, with no restrictions on the distribution of the market process.
- Ethier (1988) published 'The proportional bettor's fortune' and showed that in terms of security, an optimal policy is often to keep all wealth in a riskless asset.
- Ralph Vince wrote *Portfolio Management Formulas* (Vince 1990) in which he popularized and extended Kelly's formula under the guise of a position sizing method he termed *optimal f*.
- Thomas Cover and Joy Thomas publish *Elements of Information Theory* which includes chapters on 'Gambling and data compression' and 'Information theory and the stock market' (Cover and Thomas 1991).

- Vince (1992) wrote *The Mathematics of Money Management*, in which he weds his ‘optimal f ’ to the optimal portfolio.
- MacLean, Ziemba and Blazenko (1992) considered how an investor should make the trade-off between maximal growth (i.e. using the Kelly criterion) and maximal security (e.g. minimizing drawdowns).
- Rotando and Thorp (1992) applied the Kelly strategy to long-term investment in S & P 500 stocks, and demonstrated some of the benefits and liabilities of that strategy.
- Aucamp (1993) provided both theory and evidence to indicate that the ‘long-run’ required for the geometric mean strategy to be optimal can be quite long in risky situations, but can ‘virtually dominate’ in a moderate number of plays in cases when risk is low.
- Vince (1995) published his third book on money management, which elaborates on his ‘optimal f ’ and describes a new model for portfolio construction.
- Hakansson and Ziemba (1995) reviewed the theory of capital growth, in particular the growth-optimal investment strategy (the Kelly criterion).
- Browne and Whitt (1996) consider the *Bayesian* version of gambling and investment problems, where the underlying stochastic process has parameter values that are unobserved random variables, and derive a generalization of the Kelly criterion.
- Thorp (1997) presented a paper that discusses the use of the Kelly criterion in blackjack, sports betting and the stock market.
- Cetinkaya and Parlar (1997) provided a critique of the simple logarithmic assumption for the utility of terminal wealth and solved the problem with a more general utility function. They showed that in the general case the optimal policy is *not* myopic.
- Karatzas and Shreve (1998) published *Methods of Mathematical Finance* which includes a section on the maximization of the growth rate of wealth.
- Aurell, *et al.* (2000) used Kelly’s theory to price derivatives in incomplete markets.
- Aurell and Muratore-Ginanneschi (2000) studied long-term growth-optimal strategies on a simple market with transaction costs. On an infinite time horizon the investment-optimal strategy consists of allowing the amount of capital invested in stocks to fluctuate freely within an interval around the value of the optimal investment in the absence of trading costs.
- Browne (2000) analyzed some of the short-run properties of the Kelly strategy.

- Haigh (2000) interpreted the Kelly strategy in the context of spread betting.
- Evstigneev and Schenk-Hoppé (2002) prove that *any* self-financing constant proportions investment strategy yields a strictly positive exponential rate of growth of investor's wealth in a financial market in which prices are described by stationary stochastic processes and the price ratios are non-degenerate (provided that the investor trades in at least two stocks).
- In the first part of an easy-to-read two-part article, Ziemba (2002) introduces Kelly betting.
- In the second part of the two-part article, Ziemba (2004) considers the application of the Kelly criterion to lotteries.
- Anderson and Faff (2004) traded a simple and publicly available trading rule in five futures markets and reinvested any profits via the 'optimal f ' technique described by Vince (1990). They concluded that money management in speculative futures trading plays a more important role in trading rule profitability than previously considered by providing dramatic differences in profitability depending on how aggressively the trader capitalizes each futures contract.
- Ethier (2004) showed that the Kelly system maximizes the median of the gambler's fortune.
- Ziemba (2005) gives an easy-to-read review of the Kelly criterion.
- Poundstone (2005) wrote *Fortune's Formula* which is a fascinating study of the connections between gambling, information theory, stock investing and applied mathematics, with Kelly's system central to the book.
- Piotrowski and Schroeder (2006) explain the Kelly criterion in terms of thermodynamics.
- Leibfarth (2006) wrote a dumbed down item on money management in a popular magazine for traders.
- Fabozzi, *et al.* (2007) publish *Robust Portfolio Optimization and Management*, a guide to portfolio construction using 'robust optimization'.
- Vince (2007) published *The Handbook of Portfolio Mathematics*, new material includes his implementation of drawdown as a risk metric.
- McDonnell (2008) published *Optimal Portfolio Modeling*, an introduction to portfolio modelling using Excel and R. He combines the logarithmic utility function (Bernoulli 1738) with the use of logarithms for maximum growth of wealth (Kelly 1956), resulting in an iterated log function, $\log(1 + \log(1 + r))$, where r is return.

- Michaud and Michaud (2008) demonstrate the limitations of Markowitz mean-variance optimization, and use Monte Carlo resampling to address information uncertainty.

3 Examples

As an example of the use of the Kelly criterion, because the formula dictates that an investor should aim to maximize the geometric mean of their capital, stock A below should be preferred.

Value of stock after a year			Arithmetic mean	Geometric mean
Stock A	50% chance of £100	50% chance of £200	150	141.42
Stock B	50% chance of £0	50% chance of £400	200	0

Returning to the gambling roots of money management, Figure 1 (page 8) shows how Kelly betting on the horses can be good for your wealth.

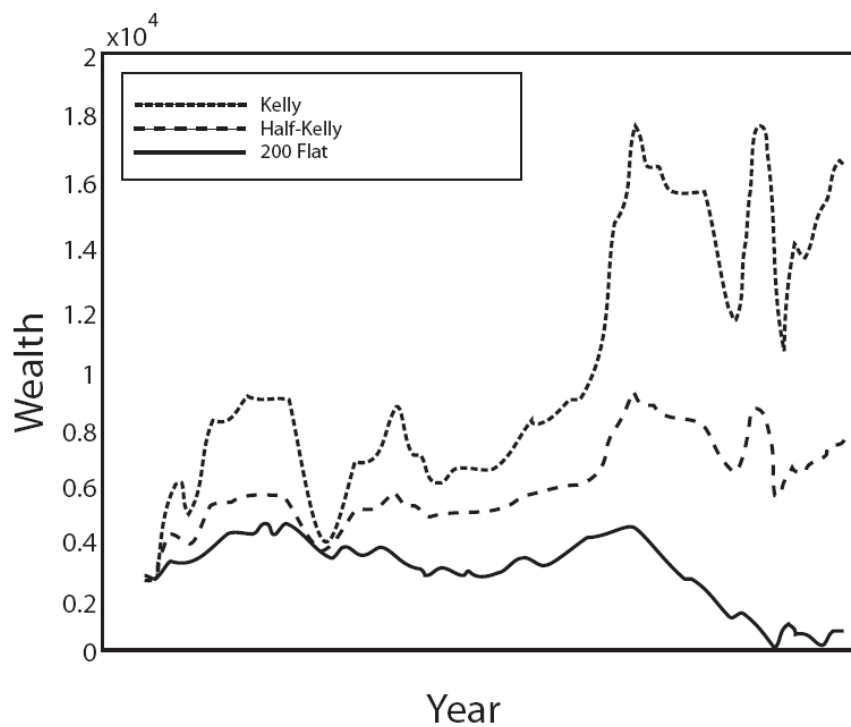


Figure 1: Wealth level histories from place and show betting on the Kentucky Derby, 1934-1998 with the Dr Z system utilizing a 4.00 dosage index filter rule with full and half Kelly wagering from \$200 flat bets on the favourite using an initial wealth of \$2500. Source: Bain, Hausch and Ziemba (2006)

References

- ALGOET, Paul H., and Thomas M. COVER, 1988. Asymptotic optimality and asymptotic equipartition properties of log-optimum investment. *The Annals of Probability*, **16**(2), 876–898.
- ANDERSON, John A., and Robert W. FAFF, 2004. Maximizing futures returns using fixed fraction asset allocation. *Applied Financial Economics*, **14**(15), 1067–1073.
- AUCAMP, Donald C., 1993. On the extensive number of plays to achieve superior performance with the geometric mean strategy. *Management Science*, **39**(9), 1163–1172.
- AURELL, Erik, *et al.*, 2000. A general methodology to price and hedge derivatives in incomplete markets. *International Journal of Theoretical and Applied Finance*, **3**(1), 1–24.
- AURELL, Erik, and Paolo MURATORE-GINANNESCHI, 2000. Financial friction and multiplicative Markov market game. *International Journal of Theoretical and Applied Finance*, **3**(3), 501–510.
- BAIN, Roderick S., Donald B. HAUSCH, and William T. ZIEMBA, 2006. An application of expert information to win betting on the Kentucky Derby, 1981–2005. *The European Journal of Finance*, **12**(4), 283–301.
- BELL, Robert M., and Thomas M. COVER, 1980. Competitive optimality of logarithmic investment. *Mathematics of Operations Research*, **5**(2), 161–166.
- BELLMAN, R., and R. KALABA, 1957. On the role of dynamic programming in statistical communication theory. *IEEE Transactions on Information Theory*, **3**(3), 197–203.
- BERNOULLI, Daniel, 1738. Specimen theoriae novae de mensura sortis. *Commentarii Academiae Scientiarum Imperialis Petropolitanae*, **5**, 175–192.
- BERNOULLI, Daniel, 1954. Exposition of a new theory on the measurement of risk. *Econometrica*, **22**(1), 23–36. English translation of Bernoulli (1738) by Louise Sommer.
- BREIMAN, L., 1961. Optimal gambling systems for favorable games. In: Jerzy NEYMAN, ed. *Proceedings of the Fourth Berkeley Symposium on Mathematical Statistics and Probability, Volume I*. Berkeley: University of California Press, pp. 65–78.
- BROWNE, Sid, 2000. Can you do better than Kelly in the short run? In: Olaf VANCURA, Judy A. CORNELIUS, and William R. EADINGTON, eds. *Finding the Edge: Mathematical and Quantitative Analysis of Gambling*. Reno: University of Nevada, Reno Bureau of Business, Chapter 12, pp. 215–231.

- BROWNE, Sid, and Ward WHITT, 1996. Portfolio choice and the Bayesian Kelly criterion. *Advances in Applied Probability*, **28**(4), 1145–1176.
- CETINKAYA, S., and M. PARLAR, 1997. Optimal nonmyopic gambling strategy for the generalized Kelly criterion. *Naval Research Logistics*, **44**(7), 639–654.
- COVER, Thomas M., and Joy A. THOMAS, 1991. *Elements of Information Theory*. Wiley Series in Telecommunications. New York: Wiley.
- ETHIER, S. N., 1988. The proportional bettor’s fortune. In: W. R. EADINGTON, ed. *Gambling Research: Proceedings of the Seventh International Conference on Gambling and Risk Taking, Volume 4*. Reno, NV: Bureau of Business and Economic Research, pp. 375–383.
- ETHIER, S. N., 2004. The Kelly system maximizes median fortune. *Journal of Applied Probability*, **41**(4), 1230–1236.
- ETHIER, S. N., and S. TAVARÉ, 1983. The proportional bettor’s return on investment. *Journal of Applied Probability*, **20**(3), 563–573.
- EVSTIGNEEV, Igor V., and Klaus Reiner SCHENK-HOPPÉ, 2002. From rags to riches: On constant proportions investment strategies. *International Journal of Theoretical and Applied Finance*, **5**(6), 563–574.
- FABOZZI, Frank J., et al., 2007. *Robust Portfolio Optimization and Management*. Hoboken, NJ: Wiley.
- FINKELSTEIN, Mark, and Robert WHITLEY, 1981. Optimal strategies for repeated games. *Advances in Applied Probability*, **13**(2), 415–428.
- FRIEDMAN, Joel H., 1976. Understanding and applying the Kelly criterion. Paper presented to the Third Conference on Gambling and Risk Taking, Las Vegas, Nevada; December 1976.
- GEHM, F., 1983. *Commodity Market Money Management*. New York: Wiley.
- GOLDMAN, M. Barry, 1974. A negative report on the ‘near optimality’ of the max-expected-log policy as applied to bounded utilities for long lived programs. *Journal of Financial Economics*, **1**(1), 97–103.
- GRIFFIN, Peter A., 1984. Different measures of win rate for optimal proportional betting. *Management Science*, **30**(12), 1540–1547.
- HAIGH, John, 2000. The Kelly criterion and bet comparisons in spread betting. *The Statistician*, **49**(4), 531–539.
- HAKANSSON, Nils H., 1970. Optimal investment and consumption strategies under risk for a class of utility functions. *Econometrica*, **38**(5), 587–607.

- HAKANSSON, Nils H., and William T. ZIEMBA, 1995. Capital growth theory. In: R. A. JARROW, V. MAKSIMOVIC, and W. T. ZIEMBA, eds. *Handbooks in Operations Research and Management Science, Volume 9, Finance*. Amsterdam: Elsevier, pp. 65–86.
- HEATH, D., *et al.*, 1987. Minimizing or maximizing the expected time to reach zero. *SIAM Journal on Control and Optimization*, **25**(1), 195–205.
- KARATZAS, Ioannis, and Steven E. SHREVE, 1998. *Methods of Mathematical Finance*. Volume 39 of *Applications of Mathematics: Stochastic Modelling and Applied Probability*. New York: Springer-Verlag.
- KELLY, Jr., J. L., 1956. A new interpretation of information rate. *The Bell System Technical Journal*, **35**, 917–926.
- KRAUS, Alan, and Robert H. LITZENBERGER, 1975. Market equilibrium in a multiperiod state preference model with logarithmic utility. *The Journal of Finance*, **30**(5), 1213–1227.
- LATANÉ, Henry Allen, 1959. Criteria for choice among risky ventures. *The Journal of Political Economy*, **67**(2), 144–155.
- LEIBFARTH, Lee, 2006. Measuring risk. *Technical Analysis of Stocks & Commodities*, **24**(12), 20–26.
- MACLEAN, L. C., W. T. ZIEMBA, and G. BLAZENKO, 1992. Growth versus security in dynamic investment analysis. *Management Science*, **38**(11), 1562–1585.
- MARKOWITZ, Harry, 1959. *Portfolio Selection: Efficient Diversification of Investments*. New York: Wiley. Cowles Foundation Monograph #16.
- MARKOWITZ, Harry M., 1976. Investment for the long run: New evidence for an old rule. *The Journal of Finance*, **31**(5), 1273–1286.
- MCDONNELL, Philip, 2008. *Optimal Portfolio Modeling: Models to Maximize Returns and Control Risk in Excel and R + CD*. Wiley Trading, Hoboken, NJ: Wiley.
- MERTON, Robert C., and Paul A. SAMUELSON, 1974. Fallacy of the log-normal approximation to optimal portfolio decision-making over many periods. *Journal of Financial Economics*, **1**(1), 67–94.
- MICHAUD, Richard O., and Robert O. MICHAUD, 2008. *Efficient Asset Management: A Practical Guide to Stock Portfolio Optimization and Asset Allocation*. Second ed. Financial Management Association Survey and Synthesis Series. New York: Oxford University Press.
- MILLER, Bruce L., 1975. Optimal portfolio decision making where the horizon is infinite. *Management Science*, **22**(2), 220–225.

- PESTIEN, V. C., and W. D. SUDDERTH, 1985. Continuous-time red and black: How to control a diffusion to a goal. *Mathematics of Operations Research*, **10**(4), 599–611.
- PIOTROWSKI, Edward W., and Małgorzata SCHROEDER, 2006. Kelly criterion revisited: Optimal bets. arXiv:physics e-print 0607166, University of Białystok, Białystok. APFA5 Conference, Torino, 2006.
- POUNDSTONE, William, 2005. *Fortune's Formula: The Untold Story of the Scientific Betting System that Beat the Casinos and Wall Street*. New York: Hill and Wang.
- RADNER, R., 1971. Balanced stochastic growth at the maximum rate. In: Gerhart BRUCKMANN and Wilhelm WEBER, eds. *Contributions to the von Neumann Growth Model (Zeitschrift für Nationalökonomie, Suppl. 1)*. Vienna: Springer-Verlag, pp. 39–62.
- ROTANDO, Louis M., and Edward O. THORP, 1992. The Kelly criterion and the stock market. *The American Mathematical Monthly*, **99**(10), 922–931.
- SAMUELSON, Paul A., 1971. The “fallacy” of maximizing the geometric mean in long sequences of investing or gambling. *Proceedings of the National Academy of Sciences of the United States of America*, **68**(10), 2493–2496.
- SAMUELSON, Paul A., 1979. Why we should not make mean log of wealth big though years to act are long. *Journal of Banking & Finance*, **3**(4), 305–307.
- SHANNON, C. E., 1948. A mathematical theory of communication. *Bell System Technical Journal*, **27**, 379–423, 623–656.
- THORP, Edward O., 1962. *Beat the Dealer: A Winning Strategy for the Game of Twenty-One*. New York: Blaisdell Publishing Company.
- THORP, E. O., 1969. Optimal gambling systems for favorable games. *Revue de l'Institut International de Statistique / Review of the International Statistical Institute*, **37**(3), 273–293.
- THORP, E. O., 1971. Portfolio choice and the Kelly criterion. In: *Business and Economics Statistics Section, Proceedings of the American Statistical Association*. pp. 215–224. Reprinted in *Stochastic Optimization Models in Finance*, W. Ziemba and R. Vickson eds., New York: Academic Press (1975).
- THORP, Edward O., 1980. The Kelly money management system. *Gambling Times*, , 91–92.
- THORP, Edward O., 1997. The Kelly criterion in blackjack, sports betting, and the stock market. Paper presented at: The 10th International Conference on Gambling and Risk Taking Montreal, June 1997. Published in “Finding the Edge: Mathematical Analysis of Casino Games” (2000), eds O. Vancura, J. A. Cornelius and W. R. Eadington, Institute for the Study of Gambling and Commercial Gaming, Reno, NV, pp. 163–213.

- THORP, Edward O., and William E. WALDEN, 1966. A favorable side bet in nevada baccarat. *Journal of the American Statistical Association*, **61**(314), 313–328. Part 1.
- VINCE, Ralph, 1990. *Portfolio Management Formulas: Mathematical Trading Methods for the Futures, Options, and Stock Markets*. New York: Wiley.
- VINCE, Ralph, 1992. *The Mathematics of Money Management: Risk Analysis Techniques for Traders*. New York: Wiley.
- VINCE, Ralph, 1995. *The New Money Management: A Framework for Asset Allocation*. New York: Wiley.
- VINCE, Ralph, 2007. *The Handbook of Portfolio Mathematics: Formulas for Optimal Allocation & Leverage*. Hoboken, NJ: Wiley.
- von NEUMANN, John, and Oskar MORGENSTERN, 1944. *Theory of Games and Economic Behavior*. Princeton, NJ: Princeton University Press.
- WILLIAMS, John Burr, 1936. Speculation and the carryover. *The Quarterly Journal of Economics*, **50**(3), 436–455.
- WONG, Stanford, 1981. What proportional betting does to your win rate. *Blackjack World*, **3**, 162–168.
- ZIEMBA, Bill, 2002. The capital growth theory of investment: Part I. *Wilmott Magazine*, , 16–18.
- ZIEMBA, Bill, 2004. The capital growth theory of investment: Part II. *Wilmott Magazine*, , 14–17.
- ZIEMBA, Bill, 2005. Good and bad properties of the kelly criterion. *Wilmott Magazine*, , 6–9.
- ZIEMBA, William T., 1987. A betting simulation, the mathematics of gambling and investment. *Gambling Times*, **80**, 46–47.
- ZIEMBA, William T., and Donald B. HAUSCH, 1985. *Betting at the Racetrack*. Los Angeles, CA: Dr. Z Investments.