

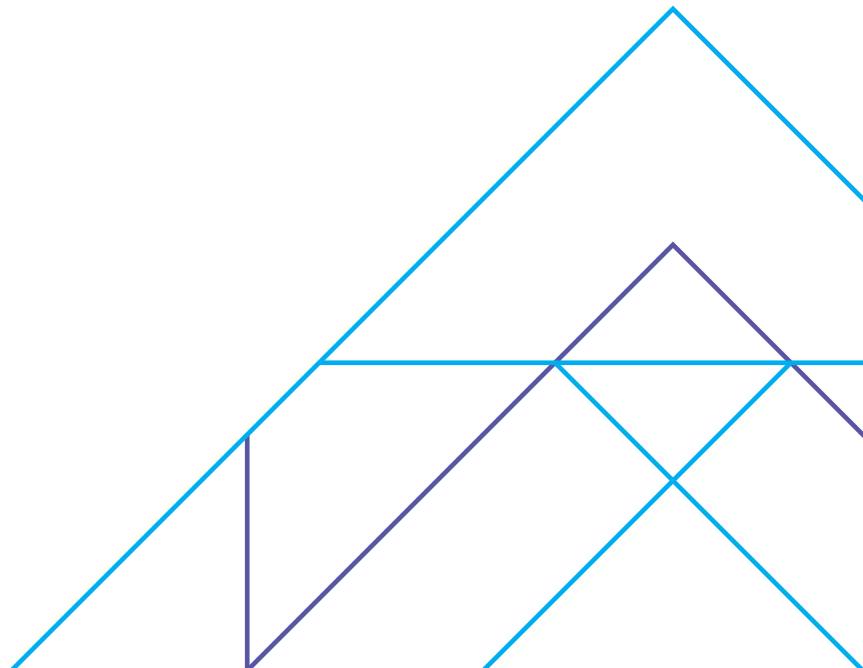
January 2018

Words From the Wise

An AQR interview with Ed Thorp

Ed Thorp, author of the famed bestseller *Beat the Dealer* (1966) and *A Man for All Markets* (2017), is regarded by many as the father of quantitative investing. He recently sat down with Aaron Brown, Antti Ilmanen and Rodney N. Sullivan to discuss contemporary challenges and best practices in investing. This is the seventh in a series of *Words From the Wise* interviews to be published on AQR.com. Following is an executive summary and the full interview with Mr. Thorp.

Although not well known among investment managers, Ed Thorp is nonetheless recognized by many as the father of quantitative investing. He initially applied his training in mathematics — he earned a PhD in mathematics from University of California, Los Angeles — to solving casino games such as blackjack and roulette, and then moved to tackling the challenges of option pricing and statistical arbitrage. His hedge fund strategies, which ran principally at Princeton Newport Partners and later at Ridgeline Partners, were profitable every year for 37 years, from 1966-2002. His recently published autobiography, *A Man for All Markets*, chronicles a man who thinks independently about how markets and games operate, and then tests his ideas against economic rationale and real world data. He currently resides in Newport Beach, California where he oversees his family office.



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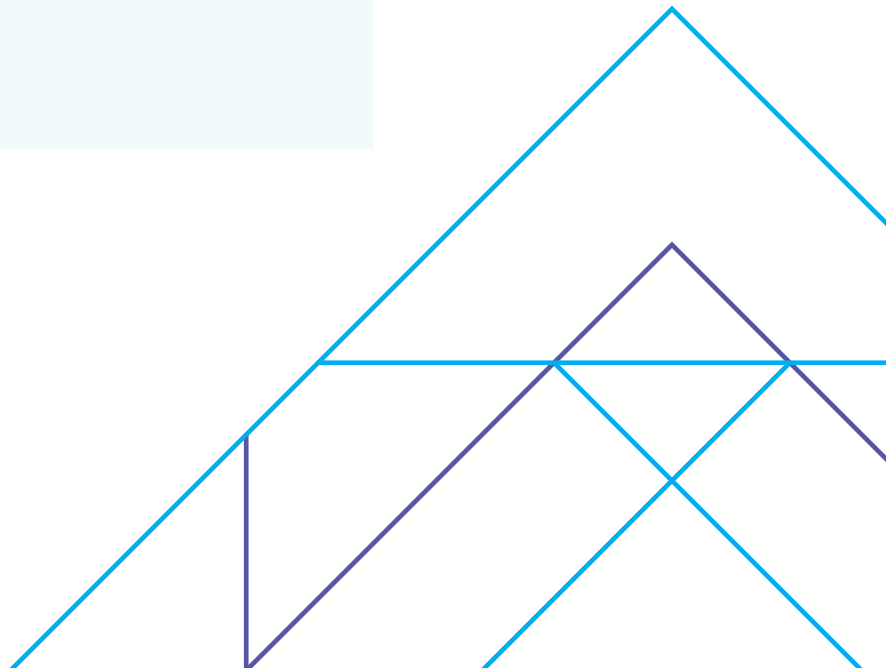
Managing Director in Equity Research, Morgan Stanley

Harry Markowitz

Harry Markowitz Company, Rady School of Management, University of California, and recipient of the 1990 Nobel Prize in Economic Sciences

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Executive Summary

Ed Thorp, a pioneer in the mathematical analysis of casino games and investing, is part of an elite group of early thought leaders responsible for creating tools and techniques for use in both gambling and modern investment management. He famously authored *Beat the Dealer* (1966), a book in which he describes in detail a mathematical system he devised for beating the house in blackjack. He then turned his attention to solving challenges in investment management, specifically option pricing — this is where we begin our conversation. We discuss how he came to investments and his thought process behind creating and implementing his option pricing model, independent of, and a few years ahead of, Black and Scholes. We then turn to get his thoughts on more contemporary topics, including factor modeling, the challenges of consistently generating unique alpha, and the current state of retirement plans. We conclude with hearing about his heroes.

Early Career

Sullivan: You came into the practice of finance not from a finance background, but as an academic from the hard sciences. In retrospect, what were some of the cornerstones of finance, if any, that would have been helpful for you to have known early in your career?

Thorp: Well, I had no contact with the academic finance and economics community at all. I was unaware of their existence. I was focused on math, physics and other things in science. In 1962 I started teaching myself about investing. I had money from my gambling experience and from writing books.

“So, my good fortune, as well as my misfortune, was that I didn't know anything about finance.”

At first, I made some investment mistakes, foolish ones that many people make. As a result, I decided to really buckle down and try to understand investments. After a couple of summers of reading, I felt that I had a good idea to pursue. I wanted to work out a mathematical analysis of common stock purchase warrants, which were similar to call options today. The idea was appealing because I could get rid of most of the variables that people commonly use to evaluate companies. Also, I could hedge the risk in the warrant by using common stock because the price of a stock and its corresponding warrant move up and down together. So, instead of having to do a lot of fundamental analysis (like go out and talk to CEOs), I just needed data for a few

readily available variables like stock price volatility and the riskless interest rate. That finding was a great revelation to me and I thought I could use it to make steady profits.

Sullivan: Were you aware of others working on the option pricing problem at that time?

Thorp: I began to discover that there were people in this vast world of finance and economics who'd been working away at this, and lots of other interesting problems. So, my good fortune, as well as my misfortune, was that I didn't know anything about finance. I didn't have any academic finance background or connections. That also meant that I had fewer set ideas going in. So, I thought things through ab initio for myself.

Sullivan: Did you realize at the time how revolutionary your options formula would be to finance?

Thorp: No, not at all. Since I had no connection with the academic world of finance or economics, I had no idea this was that important a problem, and that it would have such widespread application.

Sullivan: At what point did you become aware that others were working on this same formula?

Thorp: Around 1967 I was thinking about developing a warrant pricing formula, and as a first step I integrated the lognormal distribution to see what I would get. And then I realized that the folks at MIT, Samuelson, among others, had already done some work on it.¹ The relevant formula contained

1 See *The Random Character of Stock Market Prices* by Paul Cootner (1964).

two unknowns. One was the rate of growth of the common stock, and the other was the discount rate applied to get a risky terminal distribution for the payoff on the warrant. That's where everybody had gotten to, and they were all stuck there.

This idea didn't come right away, but after thinking about it for a while, I thought that in this situation, I could just plug in a sensible estimate of the discount rate instead of attempting to calculate a solution for every possible situation. Then, I thought, what if you were in a world that was risk-neutral? Well, then, all the various rates would become the riskless rate. So, let's try that out and see what happens — and bingo, you got a really simple, beautiful formula.

“And bingo: you got a really beautiful, simple formula.”

So then, by extension, I thought that although the various stock hedges are not exactly riskless, because it's too costly to adjust them continuously, I can adjust them fairly frequently whenever there's a moderate deviation from balance. As I have a collection of them, the deviations between my discrete adjustments and continuous adjustment are like a diversified pool of random noise. So the more positions I have, the more the deviations wash away and the appropriate discount rate becomes the riskless rate. In short, what I've got is a pot of hedges which pay out, if fairly priced, at what ought to be the riskless rate. So, it made sense to use this formula using the riskless rate for the growth rate and the discount rate.

In thinking about this just qualitatively, I realized that if a stock is more risky, then the expected growth rate will be greater but the discount rate for that payoff will also be greater. So, there's going to be substantial cancellation between the two. Maybe it's incomplete. Who knows? After some thought, I decided that this formula holds all the properties that you want in such a formula, and it's the answer in the risk-neutral universe. So, if there is a single answer, this formula has to be it. It's plausible that it's not the single answer for everything. But I decided to use it, and I did.

Sullivan: Ben Graham used to say successful investing requires you to have the courage of your convictions. How did you come to be so confident that you had solved this challenge?

Thorp: Well, I thought I had a very good formula that at least qualitatively did everything right. If it was off, it wasn't off by very much. So, now I had this tool that nobody else apparently had. But that wasn't important to me; it was just a tool for managing my warrant hedges. This was prior to the launch of the CBOE.

In talking to Fischer Black long afterwards, I found out that he and Myron Scholes had also figured out this formula two years after I did. Their related research article was not well received by the journals at that time, so, the formula wasn't published until 1972, and then another paper in 1973.²

2 See Black and Scholes (1972), “The Valuation of Option Contracts and a Test of Market Efficiency,” and Black and Scholes (1973), “The Pricing of Options and Corporate Liabilities.”

Brown: Then the CBOE opened in spring of 1973 and you were ready?

Thorp: Yes, I was all tooled up. I had my formula programmed into my little Hewlett-Packard 9830 computer. It was drawing graphs that enabled me to visually figure out hedge ratios right away, and the amount of mispricing. So, I could just put a dot on the paper, and compare the option's market price to the standard curves and know whether I had a good trade or not.

Around this time, I received a letter from somebody I'd never heard of named Fischer Black. He says, I'm an admirer of your work, and I read *Beat the Dealer*. He tells me that he had extended the static hedging idea into dynamic hedging. Kassouf and I were already aware of dynamic hedging; we just didn't put it in the book, because it would be too complicated for the readers. I used Fischer's 1973 paper to calculate options pricing. But once I plugged it in and drew a graph, I realized that his graph didn't agree with mine. So, I wondered, what's wrong here? What had happened was that, prior to the opening of the CBOE short sale proceeds were treated differently. The CBOE credited the short sale proceeds to your account, which was great; but prior to that the brokers

credited it to their own account, so they basically used your money. Once I had put in the CBOE credits, mine and Fischer's matched perfectly.

This was good, because instead of one formula, I now had three formulas, and I used a different one of the three formulas depending on the situation. When there was no use of short sale proceeds, I had one formula for long stock, short warrant and another formula for short stock, long warrant; and a third formula for the warrant valuation if you got the short sale proceeds. I gave a talk in Vienna that year at the International Statistical Association where I presented the three formula variations.³

I was initially unhappy to get Fischer's paper, because I was hoping to have the CBOE arbitrage all to myself. But, then as it happened, I did have it all to myself for a while, because people weren't very fast off the mark in using it.

Sullivan: It took a while, right?

Thorp: Right. What was great about this particular procedure — I used recursive backward integration to get the formula — was that it generalized to other probabilities, not just the lognormal distributions of stock prices. So, it was useful to have my alternate approach. I used it to solve the American put problem (the possibility of early exercise).

3 "Extensions of the Black-Scholes Option Model," Contributed Papers, 39th Session of the International Statistical Institute, Vienna, Austria, August 1973, pp. 1029-1036.

Investing Today

Sullivan: Can you discuss applications of quantitative strategies that might be useful today?

Thorp: Well, I like to put things into the context of Sharpe's principle — that active investing is a zero sum game on net. For liquid asset classes like US bonds and stocks, for instance, this means that everybody who is active, or not indexing, are collectively a big index fund, on average. That big actively-traded "index fund" is being managed, so it's also paying costs. So, a couple of percent is being drained out of that pool, compared with the guys who are paying very low amounts for passive indexing. So, these active investors collectively have a couple percent disadvantage. So, all the institutions that are battling for an edge in those liquid asset classes aren't going to get alpha collectively. They should just index those parts of the portfolio, in my opinion. Jack Bogle discusses this same idea in your earlier interview with him.⁴

Sullivan: Our Lasse Pedersen has a paper⁵ that shows that, while true, Sharpe's arithmetic doesn't apply perfectly in practice.

Thorp: Yes, Lasse points out that new stock is added to index funds through IPOs and secondary offerings and stock disappears through buybacks and bankruptcies. This may allow active investors currently to harvest as much as 25 to 35 basis points annually from a broad index fund and more from narrower indexes. This offsets some of the active manager's costs from trading and fees that I estimate currently to be around 200 basis points.

Sullivan: Where do you see additional opportunities for institutional investors?

Thorp: What I see for institutional investors is access to the more illiquid asset classes like private equity. That's something ordinary investors don't get a shot at, and it requires active management because there's a lot of work in evaluating and hiring managers. Also, some overseas markets can be an opportunity because things can be less stable, and accounting practices are less robust than in the US.

Brown: You have a unique perspective in that you started out investing in a market that was clearly inefficient and your transaction costs were very high. You couldn't do dynamic hedging, for instance, and there was a fairly limited pool of warrants and convertibles to play with. But you had very little competition as well. Then, as you move forward in time, there's more and more competition, which presumably competes down any edge. On the other hand, the market was getting cheaper to trade and there was a much broader pool of things to work with. Do you have a feeling for which of these two dominates? Was quantitative investing more attractive in the '60s, or is it more attractive today?

4 "Words from the Wise: Jack Bogle on Building a Better Investment Industry," (2015).

5 "Sharpening the Arithmetic of Active Management." Forthcoming, *Financial Analysts Journal* (2017).

Thorp: That's a tough question. I think it depends on who's doing it. For example, some hedge fund firms have been successful, including some high-frequency trading firms. But then there's a pool of money chasing alpha, most not finding it. So, I think, collectively, the pool of alternative investment money has reached a point where it's not producing much value for the investors in it. Yet there are clearly some extraordinary performers in that pool if you can identify them, and they are accepting assets.

Sullivan: Let's turn to factor investing, sometimes called smart beta; things like value, momentum, and quality. How did you think about them earlier in your career, and then how do you think about them today? Do you see them as tools for managing portfolio risk, offering extra return, or both?

Thorp: The way I thought about them initially, we had a project that I called the indicators project. The idea was to take various characteristics in the market, or factors, and see whether they historically appeared to outperform. Then, whether you could reasonably expect that outperformance to continue; that is, was there an economic explanation for it, or just a result of data mining? We turned up quite a few factors that, at least in the past, did rather well. For instance, one of them was that stocks with high earnings yields outperformed.

Sullivan: We put earnings yield together with related factors like book value, all under the category of value. We find they work better collectively over time than any individual factor standing alone.

Brown: I think of an indicator as something slightly different than a factor. An indicator says there are two sets of companies; some have this good characteristic and some of them don't. A factor is more about ranking, say between 0 and 5, and you want to buy some long and sell some short in order to isolate that factor. Did you think about it as a factor analysis — isolating that factor — or only on finding companies that have a specific indicator?

Thorp: Well, we started out thinking about just indicators, and one of the things we found, way back in 1980, was something I talk about in the book called "most up, most down" — stocks that have been most up in the last couple of weeks tend to underperform in the next couple of weeks and those that have been down the most seem to outperform the next couple of weeks. We looked at it, and felt we could make about 20% annualized with it. But the risk in the hedge was fairly large, because we had a pot of securities long that had outperformed and a pot of securities short that had underperformed, and we were already making 20% annualized with substantially less risk in other strategies. So, we didn't implement it initially.

Then in 1982, unknown to us, a fellow named Jerry Bamberger at Morgan Stanley began running a similar strategy. Fortunately for us, Jerry decided to leave Morgan Stanley in 1985 and join us. His idea was like ours with one important improvement: he grouped the companies by industry, with between three to 15 companies in each. He would only trade within each industry group, for instance oil. He was neutralizing an important risk factor common to that subgroup. There might be an interest rate factor for banking, and so forth. He had returns

similar to ours with less risk. We set up a joint business with him. He ran it and we funded it. We both put in ideas. It worked well. We ran that strategy from 1985 to 1988.

“We turned up quite a few factors that, at least in the past, did rather well.”

Ilmanen: So, while you studied many indicators, you focused on relative reversal patterns within industries?

Thorp: Yes, but we migrated from the Bamberger model as the results gradually weakened. It was producing 25% annualized for a while, then it faded down to about 15%. So we said, why don't we neutralize factors as part of the whole pot? We then created a strategy that consisted of just two big pots of stocks — one that was long the underperformers, and another one that was short the outperformers. We included 100 or 200 stocks on each side, typically, with at most maybe 1.5% in any one name. We used an optimizer to neutralize as many risk factors as we could.

Ilmanen: What types of risk factors were you controlling for?

Thorp: We decided to use abstract, or principal component factors, instead of economic factors.

Sullivan: With principal components you don't necessarily know the source of the risk.

Thorp: Right, the biggest one was clearly the

market, but then the next largest one is hard to say what it is. It was some linear combination of economic factors, and so on down the line. But only a few were important, maybe five or ten.

Brown: So, you're still buying the stocks based on a single indicator and you're using the factors defensively to reduce risk. Did you ever think about using the factors aggressively to identify the sources of value?

Thorp: That seems like a good idea, but we didn't do that. I'm sure the frontier has rolled on far and vigorously since then.

Ilmanen: Did you try to combine them into multi-characteristics attractiveness?

Thorp: We looked at individual indicators, and then we looked at the linear and non-linear relationships between small groups of them. There were a number that seemed to have non-linear relationships that were pretty interesting. We divided things into deciles, or in some cases quintiles, and looked at all the cells.

Sullivan: That type of decile or quintile ranking analysis has become commonplace now in finance research, but I don't think it was common when you were doing it in the early '80s.

Thorp: Yes. This was all done from 1980 to about 1986. One reason it was hard to get started much earlier was that the databases weren't conveniently available. We used CRSP and Compustat. Some of the unpublished papers I had in finance were presented at the annual CRSP conference held in those days.

Market Efficiency

Sullivan: You've discussed the efficient market hypothesis (EMH) in that you don't find it to be true in its strongest form. A fair point, and one that most everyone agrees with. But do you think that that the EMH is a good starting point for thinking about markets and investment strategies?

Thorp: Yes, I tell people that EMH is not true, but for you it probably is true. That is, most people don't have an edge. If you think you have an edge, it needs to be logically demonstrable. You've got to be able to defend it against a good devil's advocate. If you can't do that, you probably don't have an edge. So, I think people should act as though it's true until they can demonstrate otherwise. Having said that, in reality, markets are not perfectly efficient. There are many inefficiencies. But most of us can't see them. To me, it's not a property of markets. It's a joint property of the markets and the people who populate those markets.

Sullivan: Meaning human behaviors?

Thorp: Yes, here's an illustration. Something which at first appears random or unpredictable may actually be predictable. Claude Shannon and I built a machine to beat roulette. Roulette normally appears to be a random process. But, sometimes, way back, players exploited defects in roulette wheels. Maybe one of the frets or dividers between the pockets is a little loose, so some pockets would be preferred over other pockets, so the numbers would come up with frequencies that deviated from random to some extent. The machine we built was even more advanced, it predicted position and velocity of ball and rotor, and from that we were able to forecast what region of the wheel

the ball would fall into. We got a big edge. The machine is now in the MIT museum. So this is an example where, if you have more information about something that appears to be random, it could turn into an edge.

“I don't think EMH is quite the right mental framework for thinking about markets, but it's a good start for almost everybody.”

That's also how markets are. The problem is that, even though markets aren't strongly efficient in the sense of EMH, it's still difficult to find edges. By “edge,” I mean excess return after adjusting for risk, net of costs. Also, when an edge is discovered, the money that's poured into it makes the edge go away, because it moves prices toward correct pricing. So, I don't think EMH is quite the right mental framework for thinking about markets, but it's a good start for almost everybody.

Brown: Let's say there's two ways we could think about market efficiency. One is that the market is efficient, and the prices eventually move towards correct pricing based on some economic rationale, but the actual prices deviate from that because people mis-measure things, or have behavioral biases and so on. The second is that prices are just random, and there's no real economic connection. The pricing formulas don't make any sense. Would you put yourself in one or the other of those two camps?

Thorp: Well, I figured out most of my ideas before I knew much about the notion of efficient markets. If I'd known about EMH, I might have been discouraged. It was the same thing with gambling. When I came to blackjack, I didn't really know the history of the proofs that showed there weren't any winning gambling systems. I knew that people had established that, but I didn't know the details, so they didn't seem important to me. I just did my own thinking. Had I been trained in mathematics properly in that area, I probably never would have even considered trying to beat blackjack, because I would have assumed that blackjack is just another game that's been proven to be unbeatable.

Brown: I read your book when I was a kid. I recall there were an awful lot of people who firmly believed that this was just one more system that could be wrong — really more based on personal, maybe superstitious, beliefs. Do you feel when people were disagreeing with your work that they were basing it on a superstitious idea, or was it that people disagreed with the mathematics?

Thorp: What I found was that the mathematicians caught on right away. There was basically no academic kickback except when I initially submitted my abstract to the American Math Society it was called "Fortune's Formula: A Winning Strategy for Blackjack." The abstract committee looked at it and said oh, another crank. They were going to toss it. But there happened to be a committee member named John Selfridge, who was famous for discovering the biggest prime numbers at the time. I had known him back at UCLA and he

said if Ed says this is true, it probably is. So, they let the abstract go through. Once mathematicians saw the paper and presentation they were all aboard, including everybody at MIT.

Brown: But there were skeptics too, right?

Thorp: Yes, it was the casinos and newspaper editors who were skeptical. The general population was divided, but there were many who were enthusiastic and simply wanted the secret.

Confronting Retirement Challenges

Sullivan: Let's turn attention to the retirement challenges facing the western world. What are some of the things that we should be doing, either from an investment, savings, or spending perspective to address the retirement challenges we currently face?

Thorp: First, the retirement situation for individuals is indeed a big issue. There's a push to transfer the risk from institutions to individuals. That is, from defined benefit to defined contribution plans. I think that this is not a good thing. Individuals have a much more difficult time dealing with risk analysis and planning than institutions. Many individuals are going to come up short and it's going to be very painful for them in their later years. So, even though the institutions who have pushed for this see it in their own best interest, I don't think it's in the best interest of the retirees, and I don't think it's in the best interest of the country as a whole. Shortsighted things that people sometimes do for their individual self-interest don't tend to work out well in the long run. It's the opposite of the invisible hand. It's the invisible foot in the mouth. Everybody's working for his own particular self-interest and it's damaging for the country as a whole. A great example is the lack of willingness to address climate change. It's similar for individuals and their retirement.

Ilmanen: What about institutions?

Thorp: They also need to have adequate funding, but funding hits their balance sheet; that is, it creates a big liability and also impacts earnings. So, there's a struggle to make the company look better and to pay less into the pension fund. This creates

optimistic projections as to how well investments are going to do. But some of this is wishful thinking and results in an underfunded pension plan. I don't know how you solve that except by maybe some benchmark maximum level of acceptable return assumptions. For example, maybe the maximum is 6% returns or less. For anyone assuming higher, the law could have them migrate toward that 6% over a period of time, so the pain wouldn't come all at once, instead let their target for expected returns creep down to wherever the ceiling is. The ceiling could move with experience, but very slowly.

“Many individuals are going to come up short and it's going to be very painful for them in their later years.”

Brown: If we do that for the government-sponsored, state and local plans, this creates potential tension because they may feel the need to reduce benefits and/or raise taxes. Is that an issue we should seek to address today, or should we just hope that somehow, down the road, it'll be easier to solve?

Thorp: I totally agree with your point. There are ideas that make sense if a benevolent dictator could apply them; and then there are ideas that are politically manageable. They're often very different. The idea I threw out might work if we thought about it seriously and in some detail, but it might not be politically realizable.

A good example of that sort of problem was the Affordable Care Act. A lot of people wanted a single-payer plan, which may or may not be the answer, but many people thought gradually transitioning Medicare into a single-payer system would be good. So, politically feasible versus what makes sense from the benevolent dictator standpoint. Difficult issue. It's one that to me, is a fundamental problem of democracy: that it's difficult politically to put into place the most rational solution to a social problem. As Churchill famously said, democracy is the worst possible system ever invented... except for all the others.

These issues are real. When people retire, they must have money to spend and it has to come from somewhere. There is a rational way to figure out how much they need.

Sullivan: So far, we've discussed better funding of the liability. What about opportunities to improve on the investment side?

Thorp: Well, I've been an advisor to a couple of endowment funds. I was on a finance committee on one of them for quite a while. We had an outside advisor who set up benchmarks and suggested managers and hedge funds that would supposedly outperform, and so forth. The committee would work on this very seriously. These were smart, successful people, about a dozen, with a range of expertise. They would debate long and hard about how to allocate the assets — how much to emerging markets, how much to bonds, and so forth. And they'd fine-tune it from time to time, but mostly it didn't make much difference. I found it difficult to persuade them that all this cerebration was a waste of our time.

I also believe that investments by a large committee tend to be less good than a very small committee. But there's an exception. For instance, institutions such as Yale or Harvard may have a large committee with connections and opportunities that they can tap, that aren't available generally, that they otherwise wouldn't have access to. The network access, to me, is where the value comes in. Not the asset allocation discussion.

Sullivan: Let's turn to individual investors. How can we support individual investor success with a secure retirement through DC plans?

Thorp: For my friends and family that have enough savings to support their retirement and don't need the money in the near future, I tell them to put it all in equities and let it run. Stocks have historically outperformed over moderate to longer periods by a significant amount. I believe that the equity risk premium is real, and will lead stocks to continue to outperform in the future. So, they do that, and they've all been quite happy so far.

For many years, I've also told them to buy Berkshire Hathaway, because it's a whole collection of well-run businesses. So, it's a lot like a mutual fund that is run by probably the most successful investor we've ever seen. It also doesn't pay dividends, so returns compound tax deferred which is a lot less onerous than tax paid now. Also, if you ever need to spend some of the money, you can just sell shares. The B shares now available help with that.

Sullivan: Any thoughts on the evolution of target-date funds, and do you think that the recent growth in target-date funds, auto enrollment with qualified default investments, and auto escalation have been beneficial in encouraging savings and risk-taking?

Thorp: I find that retirement savings is individual specific. There's not one cookie-cutter answer for everybody.

Sullivan: Yes. And unfortunately, our industry is not yet able to offer more one-on-one time for DC participants in order to customize a plan that each person is comfortable with and will stick with through the tough times.

Thorp: Well, I have exactly that problem with one of the endowments that asked me to give them advice. As a perpetual endowment, it'll be there as long as the organization exists. So, not five years or 20 years, but 100 years or more. I told them to buy a low-cost index fund and stick to it, and they did that.

We did simulations to create assurances that things would work out in a worst-case scenario. Our finding was to draw no more than 2% a year from the endowment. They have a portfolio that behaves like roughly 20% bonds and 80% equities, but they feel fairly secure.

We also discussed how, in the real world, there will at times be people on the board that are more resistant to fear than others, while others may want to do market timing. So, what they've done is to make the rules such that it's very difficult to change the investment policy. That way they may hang onto this policy and prevent defections during the tough times when there's a big downturn.

Lessons Learned from the Global Financial Crisis

Sullivan: What do you find are the key lessons from the events of 2008-2009?

Thorp: One of the themes in my book is the disasters that we've encountered due to excessive risk taking via leverage. The first well-known one is 1929 when people were buying stocks on 10% margin. So when stocks would go up 10%, their equity doubled and they'd buy more. But then when there was a moderate retraction in prices, their equity was suddenly wiped out and they got margin calls that they couldn't meet. So, they had to sell, or their brokers sold for them. That dropped prices even further. We had had a leverage bubble which, when run in reverse, led to a very sharp collapse.

Maybe people learned from that, because the next crisis wasn't driven by leverage. It came in 1987, when the market dropped 23% in a single day. This was a different kind of feedback system driven by portfolio insurance. On the prior Friday, October 16th, the market dropped about 4% and the way portfolio insurance worked required investors to sell stock. A 4% drop on Friday meant you're going to sell stock on Monday morning, which led to further drops and so on. The 23% decline was equivalent to the two biggest down days in 1929 put together. So, 1987 wasn't leverage related, but it was too many people trying to do the same thing at the same time.

Brown: The S&L crisis of the mid 1980s was similar?

Thorp: There was short-term borrowing with long-term liabilities, so there was high risk taken via an asset/liability mismatch.

Brown: About four years later there was the deleveraging event in the commercial mortgage market. People in the early '80s were concerned with a several-billion-dollar loss from the S&L crisis, but the commercial mortgage market lost over \$100 billion. The little one sometimes gives birth to the bigger problem.

Thorp: Yes. Then in 1998, Long-Term Capital Management was employing very small edges with leverage for very good returns, initially. But the leverage was excessive, causing risk to be way out of proportion. There was no margin for anything bad to happen. When something bad did happen, it imploded. So, that was another disaster related to excessing risk-taking via overleverage.

And then there was the mortgage crisis in 2008-2009. Excessive risk via overleverage was behind that too. Back in the '30s, there was Glass-Steagall and an attempt to limit the degree of leverage. Then there was a gradual weakening of these restrictions and banks were able to leverage themselves again to high levels. It has been reported that the five big banks were leveraged 33 to 1 at one point. Two of them are dead now, and three of them got bailed out. We are now again seeing a possible erosion of capital requirements and this is troubling to me, especially as 2008-2009 showed that profits were privatized and risk was socialized. So, I think the moves toward deregulation are ill-advised.

Brown: One challenge with regulation is that the leverage moves other places. So, maybe the banks could be completely plain vanilla with no risk, but that's not going to stop people from leveraging. For instance, with the 1987 crash you mentioned, there was no explicit leverage. Is there a broader way to reduce the problems of leverage?

“If investors are getting bailed out each time, they're not going to learn about risk.”

Thorp: Good point. I don't know how to do this exactly, but the answer, if it's feasible, would be to protect against the collapse of institutions we can't afford to have collapse, and to let the ones that we can afford to have collapse, collapse. If investors are getting bailed out each time, they're not going to learn about risk. But if there's a real risk of getting wiped out, they'll monitor risk and have better risk management practices.

Related to this, during the 2008 crisis, the focus was to bail out these institutions, but I believe the focus should have been to put America back to work. You need people working to produce GDP. I think we lost trillions in GDP by having so many people out of work.

How would we have put them to work? We'd have something like the Works Progress Administration (WPA) or the Civilian Conservation Corps (CCC),

like we had in the Great Depression. The solution would be fairly simple, which is to pay wages that are adequate but perhaps below what would be paid in the private sector. Then as soon as the private sector is up and running it draws all those people out from the government projects. We could have been building infrastructure: roads, schools, repairing bridges and so on. We could have put millions of people to work. Those people at work would have been able to keep their houses in many instances, and they would have supplied demand for products in society and so forth.

Sullivan: What about the so-called shovel-ready projects initiated by the Obama administration? Was that effective?

Brown: That's tough because you really need to plan in advance of any downturn.

Thorp: I was thinking maybe we could put the Army Corps of Engineers to work in organizing such an effort.

Brown: Yes, although which projects get approved always end up being politicized, whether determined by Congress or by the Army Corps of Engineers.

Thorp: This is a difficult issue, but I think it could be accomplished if thought through.

Investment Education

Sullivan: Are there fields of study that you think might be particularly useful for those interested in entering into finance?

“For young people just getting started, I say apprentice yourself to somebody who's good and knowledgeable, and you'll learn the ropes much more rapidly.”

Thorp: It all depends on what part of finance you want to go into and what approach you want to take. You could take a quantitative, systematic approach or you could take a more fundamental, discretionary approach. For the latter you would study and analyze specific companies to include in a portfolio, or maybe you could focus on doing mergers or buyouts by looking at corporate structure. On the other hand, you could construct portfolios using statistical analysis where you try to allocate your resources as effectively as possible among various asset classes. For young people just getting started, I say apprentice yourself to somebody who's good and knowledgeable, and you'll learn the ropes much more rapidly.

Sullivan: How much mathematics training do you think is necessary for a finance career?

Thorp: Well, that's a very timely question for me because I have six grandchildren and three of them are triplets, all of whom are currently undergraduates at MIT. One of them spent his summer at CERN, but he wants to intern in finance next summer. So, he's wondering what kind of background he needs. He's been studying math, theoretical physics, and computer science, which seem to be a perfect background. I tell him, now all you need is some foundational education in finance, and you'll know whether you like it or not and which way to go. But, I think a deep knowledge of math, not cursory, as you might get in an MBA program, is important.

Sullivan: Would say a PhD in finance provide sufficient mathematics or do you need even deeper?

Thorp: Well, you can flip it around and say, do you want to be Warren Buffett? Then you don't need a PhD in finance.

Brown: Putting the question differently, is there a sweet spot of the right amount of mathematics to apply to these problems? Going back to blackjack, you spent considerable effort solving it mathematically, even though it didn't require advanced mathematical theory and required as much intuition as math.

Thorp: Problems come in all sizes. I spent some time with Claude Shannon. There's a book called *A Mind at Play* that just came out recently.⁶ When I read it, it reminded me of the way he thought. He just followed his interests and did what he liked to do, whatever it happened to be. He'd sit down and think about a problem for as long as he wanted and he tried to avoid distractions. He just did his own thinking. So, that's one approach that a really smart person can do.

Brown: A recent paper by Haghani and Dewey (2016) indicated that students in finance often lack the basic quantitative skills to properly think about risk.

Thorp: Yes. The authors conducted a live experiment with college-aged students and young professionals at asset management firms who were knowledgeable about investing.

The experiment went like this: each participant gets 30 minutes and \$25 to start with. Each has a computer terminal and is informed that they will flip a computerized coin that comes up heads 60% of the time and tails 40% of the time. Then they can bet as much as they want on each coin flip. After 30 minutes, time stops and they get to keep their gains up to a certain dollar limit (otherwise the experimenters might go broke!). If they reach the limit sooner, then betting stops, because they've won as much as they can. The others go on betting.

So, the question is, what betting policy should you follow? Many of the participants had no idea what to do. Quite a few of them went broke and a rather large portion of them didn't make any money. Another rather large section made some money but not a lot. The average amount of winnings was around \$70 for those not going broke. Aaron wrote a nice piece (2016) which analyzed all this in detail. Winnings should be something like \$240 if they follow optimal policy.

Brown: Yes. Very high probability that they'd win about \$240 if they used the Kelly method, which as you already know says to bet 20% of their bankroll each flip on heads, calculated as $2(.6) - 1 = 20\%$. Basically, there seemed to be two types of bettors, risk-takers who went broke and non-risk takers who bet small amounts like \$1 each time, so average winnings of even those not going bankrupt were quite low.

Thorp: Every year in Las Vegas they have something called the Blackjack Ball, where about 50 of the best gamblers in the world gather. If you were to ask any of these professional blackjack players what to do, they would have said, well, I'll just use the Kelly Criterion because it's a close approximation to an optimal solution. So, the professional blackjack players would know the answer, but the finance people did not.

6 See Soni and Goodman, *A Mind at Play: How Claude Shannon Invented the Information Age* (2017).

“The professional blackjack players would know the answer, but the finance people did not.”

This goes back to a lesson that I learned very early, casino gambling with a system where you have the edge is a wonderful teacher for elementary money management. Bill Gross, one of the founders of PIMCO, learned this early on as well. He read *Beat the Dealer* and went out to Las Vegas early in his career, and he labored for four months using the Kelly system to increase \$200 to something like \$10,000. He purportedly said it was the hardest \$10,000 he ever made. When he went to PIMCO, that thinking guided him. But instead of betting with a \$200 bankroll, he was betting billions. Same principles. It's just a matter of scale.

That's what I learned playing casino blackjack, just keep scaling up — same idea for investing in the stock market. This is not well understood. One of the reasons it's not well understood is because Paul Samuelson took offense at a chapter in our book *Beat the Dealer* called "Why are we spilling

the secret?" In that chapter, I wrote unwisely, not knowing the academic hierarchy, that the people at MIT had been working on this for 11 years, and that they undoubtedly would discover this if we didn't go ahead and publish it now. And so, he viewed himself, perhaps rightly, perhaps not, as the world's great expert on the subject.

Brown: Do you think that Samuelson's opposition to the Kelly Criterion slowed its adoption in economics?

Thorp: Yes.

Brown: I would say it wasn't until about the '90s that it was respectable for economists to discuss the Kelly criterion or the idea of optimal rules, as opposed to utility theory.

Sullivan: Thank you for sharing your insights with us. It's been a real pleasure.

Heroes and Mentors

Ilmanen: Can you discuss people that were influential in your life, heroes or mentors, maybe even people that you never had the chance to meet personally, but still feel are heroes?

Thorp: Well, I didn't have many true mentors, but I did have a few. Most notably, my father from age three to five; and then I had a wonderful English teacher in high school from grade 7 to 12, and we stayed friends after I went to college. I also had a few good professors, but they weren't really mentors, rather people that taught great classes. My thesis advisor, Angus Taylor, was very supportive. He was a respectable mathematician and eventually became Academic Vice President of the University of California. He was a good, thorough, careful, patient guy who I found very helpful. I also had encounters with people that were well known, but none of them were mentors. For example, I spent a fair amount of time with Claude Shannon; we worked about a year together intensively on the roulette project. But it was collegial rather than a mentor relationship. So, a shortage of mentors.

Brown: What about heroes?

Thorp: There are many historical figures that I admire greatly. Newton, Einstein, and Darwin among them.

Brown: Newton for his work, or Newton for his life?

Thorp: Newton for his work. He was amazing. He accomplished all these things at a fairly early age, and then he spent more energy than he put into science in religion, in being master of the mint, and in making unfortunate investments. He was a very interesting person.

Brown: You inspired a whole lot of intelligent people, some of them went into casino gambling, blackjack card counting; others went into investing, most with a chip-on-their shoulder attitude — I'm not here to just play, I am going to beat the dealer or the market. So, your work seriously changed their lives. Do you regard that as a good thing, something you're proud of? Or do you think maybe you led a lot of people astray?

Thorp: I've met and talked to a lot of those people over the years, and I think generally it was a good experience for them. And the ones who went astray, I'd say with self-interest that they would have gone astray anyhow.

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