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# Harnessing the Building Blocks of Economic Valuation, Exploring the Work of Nobel Laureate Robert C. Merton, PhD

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# Harnessing the Building Blocks of Economic Valuation

## Exploring the Work of Nobel Laureate Robert C. Merton, PhD


Robert C. Merton, PhD

Using his background and skills in mathematics and engineering, Robert C. Merton expanded a new theory for options pricing into a fundamental valuation tool that became the standard in financial markets around the world, coining the term "the Black-Scholes model." Together with the originators of the theory, Myron S. Scholes and Fischer Black, he laid the foundation that made possible the growth of the derivatives markets and provided the basis for the creation of new types of financial investments and development of economic valuation across other areas. The impact of their methodology was so immense that economist Zvi Bodie compared it with the discovery of the structure of DNA, with each giving rise to a new and important field of study: financial engineering and genetic engineering, respectively (Bodie 1998). In 1997, Dr. Merton's work was recognized, along with that of Myron Scholes, with the Nobel Memorial Prize in Economic Sciences, which cited their pioneering work and its impact on efficient risk management.[1]

Born and raised in New York, Dr. Merton earned a bachelor of science in engineering mathematics from Columbia University in 1966, then moved to the California Institute of Technology to complete a master of science degree in applied mathematics in 1967. While working on his master's degree, he made the decision to leave Cal Tech and the field of mathematics in order to study economics. As he explained in his Nobel autobiography,[2] the decision was based on his belief that economics research could have a meaningful impact on the lives of millions and that his background in math and engineering as well as his intuition for economics provided an advantage in solving complex problems. Following acceptance in the doctoral program at the Massachusetts Institute of Technology (MIT), he studied with Paul Samuelson, for whom he served two-and-one-half years as a research assistant. Dr. Samuelson's work on warrants introduced him to expected utility theory and its application to optimal portfolio selection in a static framework (Samuelson and Merton 1969). This led to Dr. Merton's papers on the dynamic theory of portfolio selection and the intertemporal optimization of lifetime consumption under uncertainty (1969, 1971) and equilibrium asset pricing and the pricing of the capital structure (1970), which formed the core of his later work on the intertemporal capital asset pricing model (1973b), the rational theory of option pricing (1973a), and the pricing of corporate debt (1974).

After completing a PhD in economics in 1970, Dr. Merton joined the finance faculty at MIT's Sloan School of Management, where he met Myron Scholes, a recently arrived faculty member from The University of Chicago, as well as Fischer Black, then a consultant with Arthur D. Little in Cambridge. The three men became interested in research into asset pricing and derivative pricing models, which eventually led to Black and Scholes's groundbreaking 1973 article on options pricing theory as well as Dr. Merton's 1973 paper that expanded the mathematical understanding of the options pricing model, in which he was the first to use the term "the Black-Scholes model." In 1988, Dr. Merton accepted a position at the business school of Harvard University, serving as the George Fisher Baker Professor of Business Administration until 1998 and the John and Natty McArthur University Professor from 1998 until 2010. In 2010, he rejoined the faculty at the Sloan School as School of Management Distinguished Professor of Finance.

Over the years, Dr. Merton's research has focused primarily on mathematical finance theory in the areas of capital markets and financial institutions. He has served on the editorial boards of several economic journals and written numerous articles for professional journals and books, including *Continuous-Time Finance*; *Cases in Financial Engineering: Applied Studies of Financial Innovation*; *The Global Financial System: A Functional Perspective*; *Finance*; and *Financial Economics*. He also has written on the operation and regulation of financial institutions, including issues of capital budgeting, production, hedging, and risk management. Throughout his career, Dr. Merton has been recognized for his ability to translate finance science and research into practice, serving as a consultant, advisor to financial institutions, and mutual fund board member. From 1988 to 1996, Dr. Merton was a member of the board of trustees of the College Retirement Equities Fund (CREF). He currently serves as Resident Scientist for Dimensional Fund Advisors (DFA), where his work includes the development of an integrated pension management solution system that addresses deficiencies associated with traditional defined benefit (DB) and defined contribution (DC) plans. As Dr. Merton observed in his Nobel autobiography, "I believe that my involvement in practice has shaped [my] research and in turn has been shaped by it, this interplay to the benefit of both."

In addition to the Nobel Prize in 1997, Dr. Merton received *Risk*'s lifetime achievement award for contributions to the field of risk management and a lifetime achievement award in mathematical finance from Boston University.

He also has been named to the Derivatives Hall of Fame by *Derivatives Strategy* magazine and the Risk Hall of Fame by *Risk* magazine. In 1993, he received the inaugural financial engineer of the year award from the International Association of Financial Engineers, which also elected him a senior fellow. A distinguished fellow of the Institute for Quantitative Research in Finance and a fellow of the Financial Management Association, Dr. Merton received the Nicholas Molodovsky Award from the CFA Institute for outstanding contributions that raised the profession to higher standards of accomplishment as well as the Kolmogorov Medal from the University of London in recognition of his work in fields of research influenced by the Russian mathematician Andrei Kolmogorov. He is a member of the National Academy of Sciences, a fellow of the American Academy of Arts and Sciences, and past president of the American Finance Association. Dr. Merton has been awarded honorary degrees by numerous universities, both in the United States and abroad, including The University of Chicago, Haute Études Commerciales in Paris, University of Lausanne in Switzerland, University Paris-Dauphine, National Sun Yat-sen University in Taiwan, Athens University of Economics and Business, Universidad Nacional Mayor de San Marcos, Universidad Nacional Federico Villarreal in Lima, Peru, Claremont Graduate University, and Saint-Petersburg University of Management and Economics.

In late November 2012, Dr. Merton spoke with members of the *Journal of Investment Consulting*'s Editorial Advisory Board about the accomplishments and challenges that shaped his career, the changing environment for DB and DC plans, and major issues facing the industry in coming years. Taking part in the discussion were Margaret Towle, CPWA®, PhD, the *Journal* editor-in chief, of HighTower Advisors; Edward Baker of The Cambridge Strategy; Geoffrey Gerber, PhD, of TWIN Capital Management; Ron Kahn, PhD, of BlackRock; Tony Kao of SECOR Asset Management; Arun Muralidhar, PhD, of AlphaEngine Global Investment Solutions; and Meir Statman, PhD, of Santa Clara University. This interview is the thirteenth in the *Journal*'s Masters Series, which presents topical discussions with leading experts and visionaries in finance, economics, and investments.

**Margaret Towle:** First of all, we appreciate your spending time with us today, Dr. Merton. We'd like to start with some general questions that we ask each of our Masters, with the first question focusing on the major factors that helped to shape your career and brought you to where you are today. Your career has obviously encompassed some great achievements, and we would like to hear about these as well as your biggest challenges and disappointments.

**Robert Merton:** Well, that's a fair question, but it's a bit daunting because the major factors were a combination of my education, of course, and a lot of good luck. I had an engineering education as an undergraduate at Columbia University, and I was able to take many mathematics courses, applied and pure, and explore all kinds of uses for math, including mathematical sociology. I had a wonderful undergraduate education where people didn't interfere with what I was learning. Then, ultimately, I ended up at the Massachusetts Institute of Technology (MIT). In my first semester there, I was advised to take a second-year economics course with Paul Samuelson,[3] even though I had no economics background. That turned out to be a major factor for me because not only did I learn my economics that way, sort of backwards, but I also came to know Paul and became his research assistant. I found out, among other things, that what I had been thinking of as an after-hours sort of pursuit actually could be a part of a day job of serious research in economics. That was a major element. Additionally, Paul happened to be working in some of the financial areas that I knew something about and wanted to pursue. So I would have to say, first, getting to MIT. By the way, I was turned down at every doctoral program to which I applied except MIT, and they gave me a full fellowship, so that was a large piece of luck. And my admission at MIT was dependent on another piece of luck, which was that the admissions person at MIT happened to recognize the mathematical people who wrote my letters of recommendation.

I'm jumping around a little at the very beginning, but I'd say getting a good education and exposure to some great people was important, but there also was an incredible amount of luck. I don't know where I would have ended up had these events not taken place. That was the main driver. Also, the fact that I had earned my master's at the California Institute of Technology, where they had the notion of students "playing" with research, rather than passively learning material, so from the beginning of being a graduate student I was fooling around with research in economics. That gave me a very big kickstart into doing the research that helped move my career forward. I hadn't even thought about teaching in a business school, and Franco Modigliani,[4] one of my other professors at MIT, came to me and said, "How would you like to do that?" So I ended up in the Sloan School at MIT,[5] which is where I've stayed and enjoyed it, and that's a major factor in how I built a career. I've always been involved full-time in academics and full-time in practice—not full-time in practice, but a lot in practice. I found that the interplay between being engaged in a serious practice and doing serious research, each fed a bit on the other, and that was an important factor. It certainly helped me in formulating models, and the models helped me in the practice. Also, my father and I were very, very close throughout life.[6] He was an eminent sociologist, so I grew up understanding a bit about the social sciences, particularly sociology and functionalism,[7] and all kinds of topics that had an influence on my research in finance, especially later on. So that's the answer to your first question.

Probably my major achievement was the work I did in developing ways of modeling the dynamics of financial markets, and securities and optimization under uncertainty. That led to a series of papers, initially, on the lifecycle problem of lifetime consumption and investment,[8] and then those

same tools led to the work on derivatives pricing. Long before coming to MIT, I was always involved in derivatives. I used to trade them, and I thought I knew what I was doing, but I didn't really know. So I came in with a lot of market knowledge about derivatives, and that helped me when I decided to work on research in that area. So I'd say the early work of that sort was probably the most fruitful and turned out to have a major impact in the sense that, on the portfolio side, we were able to reconcile expected utility theory[9] and mean-variance theory[10] and then see the real difference between dynamic intertemporal models versus one-period static models.

**Margaret Towle:** What about challenges?

**Robert Merton:** In terms of challenges or disappointments, well, on the academic side, for the past twenty years or so, I've been very interested in developing what I think of as a functional perspective on understanding how institutions change endogenously. I'd like to move away from an institutional definition of the anchors of the system to a functional one. While this idea has gotten a fair amount of traction in practice, it's had practically zero effect in academia. So I guess I'd say that's a disappointment. The other is that I had thought that the impact of finance should have been much quicker into the fields of public finance, particularly macroeconomics, but also just the whole idea of understanding macro and monetary and so forth. It is just now beginning to evolve. I've had some very interesting successes in practice, and I've had some rather spectacular failures. Long-Term Capital Management will forever be a part of my life, and I wish that hadn't happened as it did, but that's what happens when you're working in an innovative area.[11]

The other thing is a natural disappointment, so I'd say it's more in the challenge area, and that is, if you're working in financial innovation, you often have to be very patient. For example, take the option-pricing model that Myron Scholes and Fischer Black and I came up with. Myron and I took it to Wall Street in 1971. It was published in 1973. By 1975, I think it is fair to say that everyone in the options market was using that methodology, and largely that same methodology—the methodology, not the formula—is still being used today, and it is still being used as a core methodology for doing much of this type of work. So that was a very fast adaption of something that was conceived in theory and then put into practice. On the other hand, I came up with a debt model, or a credit model, that was published in 1974, and it took twenty-five years before that was widely used in practice, so one has to be extremely patient sometimes in the innovation area.

**Margaret Towle:** One of the points that you have mentioned a few times is the idea of theory and practice. If we look at the *Journal of Investment Consulting*, it is a fusion of theory and practice for the consulting advisory world, in terms of providing this information in the print medium. Given your perspective and your demonstrated ability to combine these two constructs throughout your career, what do you see as major trends in the investment industry today, and what are the issues that are important looking out into the future? For example, you mentioned the long time horizon required for ideas to take hold, so looking out five, ten, or even fifteen years, what do you see as some of the major issues in the industry?

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**Robert Merton:** I'm not sure if I have a grand vision as to where it's all going. One thing that I think is going to be very important—that remarkably is missing now—is the notion of goals-based investing. This probably won't be for twenty years, but I hope it isn't twenty years. I've been doing a lot of work in the area of next-generation retirement system design and implementation. If you look at that area, amazingly many investment products that are developed don't have a goal. They are a process, like target date funds. I only use target date funds as an example. I'm not trying to trash target date funds or criticize them, but they're very widely used. If you look at what they are, or if you read a prospectus, it says: "Here's a process. As you get older, we're going to adjust the amount allocated between fixed income and equity." They never tell you where you're trying to get or why, and that has a profound effect on a whole range of factors in investing because, if you have an actual goal for investing, you start with that, and then you derive the optimal way to achieve that goal. You'll find that you get a lot different strategies and methodologies and ways of reaching your goal than you do with the open-ended approach. So it's not that finance theory or science hasn't had goals in the sense of preference functions and so forth. It's just that they don't seem to appear in a useful or effective way in practice. At least that's my judgment. So I think goals-based investing is going to be one piece.

A second piece is the ability to take advantage of all of the information, the so-called big data[12] processing. We'll be able to create much more mass customization of solutions, and we won't have to put people in broad buckets, like age, for example, so that everybody thirty-four-years old follows the same plan, no matter their gender or other factors. That really hasn't been developed yet, but I think it will be a big area. In connection with that, there will be much greater integration of data. We all know, in principle, that to make the optimal choices for portfolios, you really need to look at all of the assets that are relevant and liabilities and the like, and that again isn't generally done. I think you can get

huge improvements in practice by being able to carry out a more integrated analysis. That doesn't mean that you control everything, but that you're aware of all of the assets and various liabilities in terms of the optimization, and that's really becoming quite feasible with the technology.

Now, the third piece really goes back to the public sector. Since the great financial crisis, we've been exposed to the focus on systemic risk. If you look at the macro models that are used, even by the Federal Reserve, they're very, very crude, and they're all certainty models to which they then add a noise term. However, the structures of these models inherently omit the fact that risk is an intrinsic part of the system, so they have no options or those kinds of structures associated with structural uncertainty. As a result, they are not likely to be very effective at picking up on the kinds of situations in which systemic risk propagation can happen. I've always thought that finance has a lot to contribute to this area of public finance, and that hasn't happened. However, it's starting to happen, and I think it will be a big area, particularly in other parts of the world, other than the Anglo-Saxon world, where the distinction between the public and private sectors in the financial system can often be blurred. These tools are going to be a big growth area and one that I believe will be for the good.

**Meir Statman:** You've developed tools for advisors, using the goals-based investing approach. Would you describe these tools?

**Robert Merton:** Sure. First, a brief background: The retirement function, as you know, is performed partly by government, partly by employer plans, and partly by personal savings. Over the past decade or so, one of the biggest shocks to the retirement function has been to employer plans. These were largely defined benefit plans, which are no longer. I mean, they're still around, but they're being closed, and no one is starting any new ones. That shock left a void as to what needed to be done. The natural thing to fill that void was defined contribution plans, because they were the only alternative. They solve the problem of the employers pulling out of DB plans by bounding their risks and making their costs more predictable. However, the problem with DC plans is that they were never designed for core retirement, and they certainly weren't designed for people who were served by DB plans.

So this set up an opportunity to create something new. What I did was to go back to basic principles and ask the question, "What would you do if you had to design a system for individuals to serve this function subject to the constraints of what plan sponsors would be willing to take in terms of risk?" This really meant that it had to be a DC legal structure, because sponsors weren't willing to take the open-ended risks of a DB plan. The way we started was to set a goal. Again, the target user really was working middle-class people in large retirement plans, and so those imposed the kinds of constraints, and then we set up the goal. In setting the goal, first of all, you're not going to be able to really find out what people want. In fact, most people, as I'm sure you know, don't really know what they want when it comes to retirement objectives. If I ask a thirty-year-old, a forty-year-old, or a fifty-year-old what they want for retirement, the first question I always get back is, "What should I want?" They really don't know, and for younger people, it's an abstract concept. So they're not going to tell you what they want, other than to say, "Well, I'd like to have a good retirement." So the goal we set up wasn't very imaginative, but it was definite. When they reach retirement, most people, if you don't know anything else about them, would like to live better if they could, but they certainly don't want to live a lot worse if they have a choice. So we have Modigliani's Lifecycle Hypothesis, in that a good retirement means being able to sustain the standard of living that you've come to enjoy in the latter part of your work life. That became the goal. Then you have to convert that goal to a financial goal, and that conversion essentially was to say that standard of living is probably best defined by income, rather than accumulation of wealth. So the goals were set in terms of income, and that income had to be protected from inflation if it's standard of living and if it's going to take care of retirement for life, and that became the financial goal.

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Once you have that, then you can come up with the design criteria that are important. The plan has to be efficient, scalable, and low-cost. Scalable is particularly important. It has to work effectively for participants who are never going to become engaged in the process. That is to say, they don't tell you anything. That's what we call—post the Pension Protection Act of 2006[13]—defaulters,[14] people who are enrolled in plans but who never give you any information. You've certainly written plenty on that, and I experienced it when I was at CREF (College Retirement Equities Fund). There are many people who are not engaged in the process and won't likely become engaged, and even if they were, it's not clear that they know what to do. The plan has to work well for such people, and so that was part of the design. It should be customized, not only individual accounts, but the goal should be individual, not collective. That's doable now, though it wasn't doable in an effective way with the technology of the past. Then you put all of this together, and you end up with a solution. You offer people a solution: the money is going to come in because they're in a plan, they have a goal, and then you optimize. That is, you set up an objective function and optimize to get that goal, which is defined in terms of the standard of living in retirement. You can do that, and you

can gather the information you need to customize it if you're clever, without ever talking to the individual.

So that's the core of the solution. Another important thing is, if people do become engaged, which eventually most of them will, that you only give them meaningful information and meaningful choices, and those are very few. Here's an example from the auto industry that illustrates meaningful versus important information. If you were buying a car, you go to the dealer down the street, and then you come to see me, and I'd say to you: "Well, you know, the guy down the street is a good guy. His engine has a 9:1 compression ratio. My engine has a 9.3:1 compression ratio." Now you're smart enough to figure out that first, compression ratio must be fairly important or otherwise I wouldn't mention it, and second, higher must be better or I wouldn't mention it. But can you convert that increase of three-tenths in compression ratio into something that matters to you, such as better gas mileage, faster speed, or more reliability? I doubt it. I can assure you that the compression ratio is important for the function of the car for all of those things, so it's important information, but it's meaningless information to you the car buyer and user. It's not meaningful, so that's the kind of information we wouldn't give to individuals.

In investing, if you have a goal—now think retirement—there are fundamentally really only three ways you can improve your chances of hitting that goal. You can save more, you can work longer, or you can take more risk. I don't think there's a fourth one. If you have one, I'd be happy to hear it.

**Meir Statman:** You can lower your standard-of-living goal.

**Robert Merton:** No, because I said we had a fixed goal. So, given the goal, there are only three things you can do, and then of course you can rate that goal against other objectives. But if you accept the notion that when you do engage people, you want to offer only meaningful choices, then really the only meaningful choices for people are those three things, given the goal. Now they may want to change their goal and get feedback and so forth, which this does, by the way. However, the point is, almost all of the other factors that we see, at least risk-return frontiers, asset allocation, glide paths, etcetera, etcetera, no matter how intuitive you make it, are like telling you the components of engines when you're buying a car. To me, it doesn't make sense as a way to approach this on a mass scale.

By the way, DB plans were an institutional way of performing that function. If you're a twenty-seven-year-old who enrolled in the old DB plan, they'd tell you: "You'll work for the company for the rest of your life. When you retire, you'll get an income based on number of years of service and your latter years level of salary, and that income, combined with Social Security, ought to be adequate for you to sustain your standard of living." That's a thirty-second speech, and the next time you have to think about it is when you retire. Now that's idealized—we understand DB plans have a lot of aspects that don't fit the modern labor force, but the point of it was that you didn't tell people about all of the workings under the hood of a DB plan, all of the investments, and everything else because that's not meaningful to them. So the attempt here is not to replicate a DB plan, but rather to provide a solution and to have the characteristics that make sense. So that's a long-winded answer.

**Meir Statman:** Just one clarification. In your program, do you allow people to make changes in all of the levers that you mentioned?

**Robert Merton:** Absolutely. And that's all.

**Meir Statman:** Yes, and I can see that.

**Robert Merton:** Okay. So it's very different, in that sense, from what you usually see in a DC plan. Plus it's integrated with other retirement assets, and as you know from portfolio theory, that's very important.

**Ed Baker:** Is it integrated with other personal assets as well?

**Robert Merton:** It could be, but as a practical matter, no, because that would mean that you would have to get information from the person. My view is that the system has to work, at the extreme, if you never have any contact with the person. Also, the information that you get from people is often highly unreliable, e.g., what your house is worth, that sort of input. You can do things to fix that, but the answer is, of course, someday, if you have efficient ways of gathering information that's reliable and happens on a regular basis, sure, you'd want to do that. But this is not a financial plan for the entire life-cycle of the person. This is just solving one important piece of it, which is the retirement part.

**Ron Kahn:** It sounds like you're focused on, as you said, working/middle-class people, so maybe their house is the other major asset they have, but they're not going to have a lot of other investments.

**Robert Merton:** That's right. High-net-worth people and even upper-middle-class to well-off people—well, there's lots more to be done for them, but retirement for working/middle-class people was the particular problem for which this solution was designed. It can be used for wealthier people, and you use it in components and so forth, but this was the problem. The challenge was that you suddenly had millions of people around the planet who were receiving this part of financial services through plans that were no longer going to be there and finding a way to fill that void in some efficient way. The technology can be adapted to the most-sophisticated investors, but that's not what this solution is designed to do.

**Ed Baker:** One of the interesting differences between DB and DC plans is that DB plans define an income level that you're going to receive, whereas the DC plans are focused more on a wealth level. How are your goals specified?

**Robert Merton:** Income level. Absolutely. That's why this plan was designed with the first step of setting a goal, and the goal is standard of living. For most people, when you press them, a standard of living is defined in terms of income, not by an accumulation of wealth. If you have $5 million, tell me what standard of living you can support. You can't answer that for me, right? With the thirty-year TIPS (Treasury infla-

tion-protected security) currently trading at 30 basis points or so, that's very different from 300 basis points, that is, you can have the same amount of money invested, but very different incomes, and it's not sustainable. So the answer is an income goal. By the way, that's quite important because the risk is measured in terms of that goal, not in terms of your wealth, the way it's normally done, so the risk-free asset is not a Treasury bill. In fact, a Treasury bill is very risky, as we are well aware.

**Tony Kao:** I used to be with a large corporate pension plan. We all know that DB plans have become less relevant in terms of providing individual retirement. From your perspective, as an academic as well as a practitioner in the DB world for years, looking back, in terms of providing secure income to retirees, what went wrong with corporate DB plans or, as a separate question, with public plans?

**Robert Merton:** Actually, they are similar problems. I mean—and this is not a Monday morning quarterback description, and I'll even recuse myself from myself—many people have written for a long, long time about the whole process in which contributions were determined in employer plans. Let's just stay within the United States, although there are similar issues in the United Kingdom and elsewhere. First of all, actuarial science is a very strong, powerful science. It was around long before finance emerged as a field, but actuaries' approach to modeling is not a very good one for dealing with financial market risks. The biggest problem is projecting, that is, treating expected returns as if they were a sure thing. A corollary of that is that stocks, or risky assets, in the long run aren't risky. The latter is just not true. I rarely make such absolute statements. It's not true theoretically. It's not true empirically. By the way, if you do believe it's true, do you know where you could best use that idea? I have the following proposal. What has a longer time horizon in the United States than pension funds? The government, right? At least I hope so. So why don't we have the government issue trillions of dollars in debt and take that money and invest it around the world in stock markets and other risky assets? If you really can, in the long run, get higher returns virtually risk-free that way, then you have a money machine, because you borrow at 2 or 3 percent and you earn 7 percent. If you do that on a large-enough scale, you can solve not only the pension problem, but you can fund the entire U.S. government without any taxes. It's the same principle. You laugh, but you have to say, "Hmmm, maybe, even before we get into the mathematics or anything, there's something strange because the principle is the same." Plus, by the way, unlike other long-term investors, the government has a central bank, so if it has any short-term liquidity problems, it can handle those, too.

The reason I bring that up is because, if you look at the accounting, which leads to what the contribution rate should be, that accounting has always, in one way or another, underestimated liabilities. Now it's true that some of the smoothing by actuaries at times overestimated liabilities because, in the days of high interest rates in the 1970s, they were averaging data for the past five or ten years, so there were transitory effects. However, the overwhelming fact is that we didn't put in enough funding, and we treated risky assets as if they were risk-free. The extreme of this, which recently got reaffirmed in the public sector in the GASP (Governmental Accounting Standards Board) and in the Pension Relief Act of 2010,[15] is that you can discount your liabilities at the expected return on assets. Now there's no place in finance where that makes sense. It has an even more perverse effect that says the more risk you take with your assets, the lower the value of your liabilities and the less you have to contribute. So you have a system that feeds off itself. Now I'm not being capricious. I'm saying that, if you look at the whole system, that's the way it evolved, and it works well until it doesn't work. It took the events of 2000–2002 to finally bring it home, as world stock markets fell, world interest rates fell, the weaker industries—steel, autos, and so forth—went bankrupt, and chief executive officers around the world came to recognize they had more risk in their pension plans than they had in their businesses. It was the most leveraged debt on the planet.

Just quickly—do you recognize that the risk of a typical corporate DB plan is identical to the risk of entering into a total return asset swap? Say you had $100 in assets and $100 in liabilities, so you're fully funded. If you wanted to have no risk in the pension payouts, you would immunize, right? You'd match funds. I don't say we should do that, but that's the zero-risk benchmark. If the average large corporate pension plan had 60 percent or 70 percent of assets in risk, what's the change in risk from that? Well, you'd be substituting receiving the total returns on, let's say, equities and paying the total returns on fixed income, i.e., long-dated, long-duration fixed-income assets. Well, that's a swap. I receive total return on the stock market, and I pay the total return on long-duration bonds.

You asked me what went wrong. I'm saying that we were taking enormous risks in this industry, huge leveraged bets in our pension system, and in the 1990s when stock prices rose almost every year, that worked very well. In fact, everything was fine. When you make a huge leveraged bet and the markets are up, you win, but when you lose, it's big. Now we have the $3-trillion underfunding of public employees' pension plans, and that's for accrued current benefits, not future. So that would be my answer. In fairness, I think there are additional factors, such as the mobility of the labor force and so forth, but the biggest one was that. I didn't see employees marching on their companies trying to get rid of their DB plans. They're very happy with them.

**Meir Statman:** You spoke about luck and serendipity and their roles in your life. It seems that academics are inclined to credit luck for much of their success, whereas people in the profession tend to credit skill. Can you speak about luck and skill in the investment profession?

**Robert Merton:** There are various ways to take a cut at that, but I think uncertainty in risk is very high. That translates into saying that we call it luck and that perhaps we can

measure and manage risk, but we can't control it. Not just in investing but, for example, in all macroeconomics, we'd blame the government, or we'd credit the government. The degree of control that we have over the economy and in being able to forecast stock markets or anything else is rather limited, and we know it objectively when we look at the numbers. However, we always act as if we have a much higher degree of control. If you think of risk or uncertainty as saying that a lot of what happens to you is luck, that may be one response. I'm not sure that's what you're asking for.

**Meir Statman:** Yes, this is what I have in mind.

**Robert Merton:** You mentioned serendipity, and I know a little bit about that. The nature of serendipity is luck. It's a kind of good luck. They say that people who work harder seem to be luckier than others. If you have organizations that are designed to benefit from chance events or that allow capitalization on chance events, it's true that what happens to them is lucky, because you couldn't predict the event. However, when that event occurred, the question is how well did that organization capitalize on it? That's the subtlety of luck. If you say it's just pure luck, so what? In investing, I can believe that there are lots of events that aren't forecastable. You can't know in advance what's going to happen, but you might be able to organize your structure's thinking, the people, the investment process you use in ways that capitalize fully on positive events so that it comes under that combination of chance and luck somehow, and you appear to be luckier. Your organization will appear to be luckier than others. Does that make sense to you?

**Meir Statman:** Yes, but I'm also wondering whether investment managers are able to switch away from attributing 80 percent of returns to skill and 20 percent to luck, when, in fact, it is more likely that 80 percent should be attributed to luck and 20 percent to skill.

**Robert Merton:** People say that, but do they really believe it?

**Meir Statman:** I don't know. You've spoken with many people, and so have I. I think they do believe it, and you see that even in the political arena where people think that the president, for example, can control prices.

**Robert Merton:** Well, the case of the president is just wrong, but then again there's a feedback system there because the president doesn't get up and say, "You know, I have only limited things I can do, and if events come out well, I'm going to do the best I can, but a lot of that is not going to be under my control if things come out bad." That doesn't happen, so there's a feedback system that tends to encourage that thinking. However, I just don't believe those percentages hold up to empirical fact. I think most people, when they look at the data with the other side of their brains, know it. No one really believes that they have 80-percent skill/20-percent luck, you know, unless they have inside information, which is illegal to trade on.

**Meir Statman:** Maybe they don't, but surely their investors do. Just look at the flow of funds when a particular fund does well, and money flows into it. It seems like investors, at least, attribute the high return to skill rather than to luck.

**Robert Merton:** The other thing to consider is that while it may be very difficult to outperform positively, there are any number of ways in which to lose, e.g., transaction costs, turnover, all those factors. To the extent that someone can improve upon inefficiencies, you really can get superior performance that, incrementally, is predictable or fairly certain. Another factor is how performance is measured. For example, when we look at the returns on benchmark stock portfolios, while we include dividends, we don't include stock loan fees. So all I have to do is, in some sense, figure in stock loan fees, and I can pick up basis points on any index, just because it's an incomplete measure. You have similar situations with inclusion trades where you have institutional rigidities. If I'm a literal indexer, I'm forced to do the four o'clock closing trades when the index changes, particularly in the mid-cap indexes and others where the stocks move in and out reasonably frequently. That can be pretty expensive, so people have figured out that, if they don't slavishly do those trades, they can pick up basis points there. That's not a matter of luck.

**Ed Baker:** May I ask a slightly different question? You mentioned before that you think financial economics is now beginning to influence policy and macroeconomic decision-making. Can you comment on how you think that is actually occurring?

**Robert Merton:** The way I see it, this is driven by need. By the way, a fellow with whom I've written some papers and who over the past decade has devoted his life and passion to this idea is Dale Gray[16] at the International Monetary Fund (IMF). He's written a book and also many, many papers where, in looking at the propagation of macrofinancial risk across and within sectors, he essentially models all of the interchanges, interactions, particularly the guarantees, but not just the formal guarantees. As you know, every debt issue implicitly has a guarantee in it, even if you guarantee it yourself. We've seen formal guarantees given by governments, and we have surely seen huge implicit guarantees. Now, those are options, and options not only are nonlinear in their response to the underlying investment but also, depending on where assets move and so forth, what they call the delta can change dramatically, so the sensitivity of the value of the guarantee to price changes in the assets guaranteed can change dramatically. None of that is embedded in anything that the Federal Reserve or the macroeconomists do because their models are basically certainty models, and options, like all insurance, have no structure, no purpose in certainty models. So they tack onto a certain model some Monte Carlo simulations[17] of error terms, and the effect of that is simply to make every sample path act as if it's certain, in the sense there's no feedback. If volatility goes up in a typical macro model, you don't get a change in value, a change in risk of the various interchanges across this. What Dale Gray and his work have done is essentially model all of that using the notion of contingent claims analysis (CCA),[18] and it's generated a lot of interesting results. It's produced some very dramatic comparisons between this kind of model and the standard macro model for financial stability and risk

propagation in terms of showing how much is left out with the standard model.

This notion is beginning to take off. Gray is in perpetual motion around the world, ministries of finance, all of the central banks. Of course, hedge funds are also interested, and other large investors are paying attention because they are interested in how it all propagates. Why? Because of need. People are recognizing that much of what happened in the financial crisis and afterwards was the consequence of not taking account of these factors. At the time they talked about large, highly improbable, and unexplainable shocks that were not anticipated in the assumed distributions—events of ten standard deviations. I don't believe it was ten standard deviations. I believe that the sensitivity of all of these guarantees got much higher because assets fell, and the standard linear models didn't pick that sensitivity change up. What they viewed as a ten-sigma event really was a two- or three-sigma event, but measured with the wrong sensitivity factor. I think that the ways of looking at events like this are finally going to have an impact. These models are informed through market variables as well as inputs, and they promise to be able to do much more serious simulations of what can happen to the system. I'm somewhat hopeful that that's going to happen.

"Of course, hedge funds are also interested, and other large investors are paying attention because they are interested in how it all propagates. Why? Because of need."

Some other work along this line in which I'm currently involved is understanding the connectivity of all of these entities, sovereigns and so forth, and measuring and creating maps of connectedness. You get some really fascinating results on these maps as to how things looked before the crisis of 2008–2009 versus the way they look after, up to today. There's a lot that can be done using what I would call market-proven techniques such as CCA, tools that are well-understood in finance. We've had a great deal of experience and practice using these tools, and the way you address things in this new application, as far as I can see, really hasn't been used, certainly in policy in the past. I don't see it being used in the sense of predicting GDP (gross domestic product) growth so much as being used to deal with the elements that are missing from the models now, which is structured risk.

**Geoff Gerber:** You talked about the DB side earlier, so my question relates more to the DC side. I've read your analogy that investors see their retirement programs as similar to a car and that all they care about is the performance and not the inside workings of the car. I know you've done a lot of work at Dimensional Fund Advisors on the whole idea of dynamically optimized portfolio strategies. So, from a fiduciary perspective, do you see the Managed DC approach or the target fund approach really changing the responsibilities from the employer to the employees? How do you see the fiduciary breakdown of that?

**Robert Merton:** Of course, you understand I've chosen a particular path, so understand that in my response. I didn't design the product by picking something out of a bucket. Just so you understand that this is my opinion and, obviously, I could be wrong, or there could be other views. That said, I truly think that most sponsors want to do the right thing for their employees. Beyond that, if trustees and sponsors are thinking about fiduciary duty, I actually think, in a world of DC, that they are going to be much better off with something like Managed DC. This is a narrow answer to your question.

The main reason Managed DC was designed was to help provide the best services for achieving the good retirement goal, at a reasonable cost for the participants. However, I believe it also offers plan sponsors more protection for fiduciary duty because, if you look at what it does, first of all, it sets income targets that make sense. It looks just like, in that sense, DB or Social Security. It's clear what you're trying to do for people. The goals are always made clear. At the same time, it's an integrated solution, so it shows seriousness in the sense that you're providing a solution, not a bunch of parts left on the driveway for someone, usually the participants, to assemble and, if it doesn't work, that's their problem. That's not going to fly in the world of the future. I'm not a lawyer, but I think any sponsors or consultants who are hanging on to some of these narrowly defined legal ways to say that they are not fiduciaries or they won't be fiduciaries are fooling themselves. Because, as we translate the core of employer retirement plans into DC—this is not tomorrow, but over time—if something goes wrong, if we have general advice that we put everybody into, let's say, some investment strategy that doesn't pan out, and we have a macro problem in the industry (I'm not talking about a few individuals but about a whole generation invested in such a way that they're not going to make it in retirement), the idea that the government and the people are just going to say, "Too bad for that cohort, tough luck," is not likely to be the answer. And I don't think the answer is going to be that the government will say, "We made a mistake." People are going to want to find out, "Who is it?" It's like with asbestos or smoking. It's not what the rules and circumstances were at the time you made the investments. It's what the rules are when disaster happens, and when it happens can be ten or twenty years down the road.

So I think Managed DC really tries to do the right thing for people. It tells them what's informationally useful. It doesn't ask them to read prospectuses or try to make judgments among investment managers or any of the other kinds of things that they're not equipped to do. I don't care

if they have 180 IQs and are finance professors or brain surgeons—they don't have the time, interest, or training to do that. So, ultimately, relying on individuals to make those sorts of decisions seems, to me, to be a losing proposition. On the other hand, in our Managed DC plan,[19] for example, we have an alert system for people who have never even been in our offices. When they fall below a certain level of probability of success relative to their goal, they are contacted, and they are told, "You've got a problem, and we can help you address it."

**Geoff Gerber:** So they can change their allocation as a result?

**Robert Merton:** No, they don't change their allocation. See, you're already thinking in terms of asking them to make a technical decision about allocation. I'm sorry—maybe you weren't talking about asset allocation.

**Geoff Gerber:** Right, to different funds, or different targets.

**Robert Merton:** Different targets maybe. As Meir mentioned earlier, they can change their goal. They can say: "Look, the goals I've set are higher than I'm willing to attempt. I have no way to get there. I'm going to reduce my expectation or reduce my goal." But, principally, as I mentioned earlier, there are only three things they can do to improve their chance of reaching a goal, and that's to save more, work longer, or take more risk. Anything else you ask them to do, to my mind, is dysfunctional, because they're not in a position to translate those decisions into anything useful. So, as a sponsor, if you provide a way of taking all of the technical factors and performing your role, not of guaranteeing anything, but of using yourself and your consultants to work with the provider of the plan, that's where the gatekeeper should be. You may say, "Well, that entails fiduciary duty." Well, you've got fiduciary duty, whether you carry it out or not.

The question is how you perform that duty. The way I see it—and I'm not trying to be an idealist here, I'm being very pragmatic—if I could show there was a process by which we designed a solution, we worked with the best experts we had and our consultants, we made our best efforts there, continued to monitor on an ongoing basis, we're cognizant of all of this, and we give participants the facts and feedback, just the way a doctor's report gives you the facts from your checkup. We don't tell participants goody-goody stories. We don't try to make them feel good. We tell them the facts, and we tell them what they can do to help themselves. If you have all of that, along with the alerts, then you have a record. If you send someone an alert every month for twenty-five years, that's 300 alerts saying: "You know what? You're not going to make it in retirement unless you change what you're doing. Save more or work longer or take more risk." Then they don't make it. It's rather hard to get a legal case out of that. You have a record that you sent them alerts. It's like your doctor saying: "Your cholesterol is 300. You can take statins, exercise, or change your diet. We can fix it." Then you don't do anything about it for twenty-five years, and you drop dead. It's very hard to file a suit against the doctor if you have 300 messages documenting that he or she tried to get you to take action.

That's a fast-pass answer, but I think it's the right thing to do. I also think it's the wise business thing to do, and that's true for consultants helping plan sponsors as well. The idea is that you recognize that you have a fiduciary duty or responsibility that's going to evolve, and if you follow this sort of strategy, that's the best protection. Some people say, "Well, if we get involved in any decisions, that makes us a fiduciary." That's the mindset that got us target date funds. I would love to be on the plaintiff's side when you get up there and say: "Everybody who is age thirty-four should have this same allocation. Everybody who is age forty-two should have that allocation." I would love to adjudicate that, because I'm going to get a forty-two-year-old male who is making $40,000 a year and a forty-two-year-old female making $125,000 a year, and I'm going to put you on the stand and ask, "These really are comparable, huh?" Put it this way. These core retirement decisions are probably the second most-important decisions people have to deal with beyond their health and medical. Would you be willing to go online and get your meds dispensed on the basis of your age, not even taking into consideration your gender?

Retirement funding is a complex problem. In judging target date funds, you can say that you've looked at historical data, and you can show all the facts, but it's really just common sense. Why would you ever think that such a complex problem as a lifetime retirement accumulation could be sufficiently solved with a single variable, i.e., age—and you don't even have a stated goal? I've taken time on this because I think it's a very important point. The industry has to learn and accept, if they don't already, that there is no safe harbor created by turning these matters into mechanical rules and thinking that they can say, "Well, as long as it's a mechanical rule, I don't have any fiduciary responsibility." I think that, first, it's a lousy way to treat people, and that's the first order for getting into trouble, and second, I don't think it's likely to hold up.

**Arun Muralidhar:** My question probably ties up everything that's been said so far because I've also seen, in the past twenty years, the bad use of finance theory in investment decision-making, both on the DB and DC sides. However, I wonder whether the academics also have failed the industry. When I look at reality—and you've hit on one very important point, which is liabilities and Modigliani's lifecycle concept of investing—the second thing that is practically the case in all investment decisions is delegation of investment decision-making from principals to agents. I'm wondering whether finance theory for asset pricing should have started with what I call relative asset pricing theory, where it's relative to liabilities and relative to the risk that the principal is willing to delegate to agents. Then the CAPM (capital asset pricing model) becomes a very specialized case of a much more relative theory.[20] Would that have helped avoid some of the problems that we've seen over the past decade?

**Robert Merton:** There are compound questions within your question. First, the most direct one to answer is on the asset pricing model. Let's not call it an asset pricing model

because the asset pricing model, strictly speaking, is how assets price in equilibrium. In the normative space where I'm managing money for you—or would you rather stick with asset pricing? That's a much longer discussion.

**Arun Muralidhar:** Let's keep it simple.

**Robert Merton:** Yes, the simplest one, where you would then come to, if you like, an asset pricing model. A normative model simply says that you want to use the goals to begin with, and then from the goals, you derive, if you like, what the liabilities are. The liabilities, in this case, are that I want to have some kind of consumption pattern. Think of it as an Arrow type plan.[21] Then you should measure as numéraire,[22] or—if you like—all risk and return, in terms of that metric. So the risk-free asset, for example, for retirement would probably translate into an inflation-protected lifetime annuity at the proper level. That should be what you use as the risk-free asset. That's what you should use as numéraire, so what immediately happens is that you transform all of the assets, risk-return characteristics, in some cases quite dramatically. So a Treasury bill, which preserves capital, is the risk-free asset, if your goal is capital preservation. That's a very risky asset in terms of an income goal, so you'll get very different risk-return characterization. However, the bottom line is that you don't have to transform all of the theory that we've developed over the past forty or fifty years. You don't need a new theory. I'll give you a simplified example: All you need to do in that case is change the numéraire. But when I say "all," that could be very important. Your point is that could be very important, because it has very different implications for how we measure risk.

In fact, let me just mention this now. In the area of regulation where I believe most people are truly trying to do the right thing, you are hearing more and more about the idea of putting in floors as a requirement. Certainly in Europe, it's very, very common. Some regulators are saying that investors at least ought to get their principal amount back, and they're defining those floors in terms of wealth preservation. In reality—and I think no one here has disagreed—for retirement, you're interested in income. You're not interested in stability of capital. You're interested in stability of income. If that rule on floors—which, in some regulators' mindset, is a good, prudent thing—is passed, you could not put clients into a U.S. Treasury strategy that matches a long-duration annuity, which is the risk-free asset. Why? Because if interest rates go up, the value of that investment could fall below par, in which case you would have violated the rules. So do you see the irony? In the name of trying to make things safer for people, you have ruled out putting them in what everyone would normatively agree is the risk-free asset, by using the wrong measure, the wrong numéraire. So that's a dramatic—simple, but very dramatic—example of well-meaning legislation that well-meaning people think is a wise idea, and in reality, they've just ruled out the possibility of putting people in the asset that's the safest.

This is the kind of area where, to answer your question, I think academics can be very important in pointing out the irony, and the industry ought to, also. They ought to help regulators understand that some of the things that seem intuitively good maybe aren't. So I think your question is rooted correctly, but I'm not sure that it takes any kind of revolutionary transformation of finance science. It takes the transformation of the implementation of that in practice and regulation and so forth.

**Margaret Towle:** That's a great point. Dr. Merton, is there any area that we have not covered that you would like to discuss, or do you wish to make any concluding comments?

**Robert Merton:** Since I point this out to every group, Myron Scholes and I did not get the Nobel Prize for the Black-Scholes formula, but for our work with the late Fischer Black on a new methodology to evaluate derivatives. So the first point is the formula was not the important contribution, even though everyone talks about it. The formula was a very special case of the methodology, and today the formula is rarely used for anything other than standardized measures in practice because, in more than forty years, the methodology has developed much more sophisticated ways than the simplified assumptions underlying the formula. That's one part.

But now we come to the broader issue that I wanted to touch on. That is the issue of models. You've heard people talking about the crisis, about bad models, or about how we have to get rid of the models. I would just say that I don't believe that "Is something a good model?" is a well-posed question. I think you have to look at a triplet. You have to look at the model, who is using the model, and what the application is. What you will find is, even in as tightly defined an area as derivatives, that if I'm making a nanosecond-to-nanosecond market in derivatives, I use a very different model than if I'm performing an evaluation of the capital structure of a firm or evaluating employee stock options. The reason is that all models are abstractions from complex reality and therefore incomplete. You have finite resources, so you put more weight in the model on the parts that are most important for the application. The reason I'm going through this is the abstraction issue in modeling, but I think that's often forgotten. You can't evaluate a model in the abstract. You have to evaluate it in the context of both the user and the application, and that approach will help clarify and identify what are so-called good and bad models. Since the topic of models keeps coming up, I thought that might be worthwhile to mention.

**Margaret Towle:** I've often heard the quote, "All models are wrong, some models are useful."[23]

**Robert Merton:** Well, yes, models are wrong because they're abstractions. Just as an aside, an example of this that comes to mind involves a trip I took to Geneva last year. When the plane hit the runway, it was a beautiful landing. The pilot came on and said: "Ladies and gentlemen, I just wanted to tell you that I did not land the plane. The computer system here did, but I thought I'd wait until you were on the ground to tell you." I thought about it, and I said, "Would I fly in a plane without the pilot?" and I said, "No." Then I thought longer about it, and I still said, "No." The precise reason is

that, as good as that computer model was, it's a model and thus incomplete, and therefore there will be situations that are outside the bounds of that particular model. That's the reason we put a pilot in the plane, because that's the best thing we can think of to deal with that unstructured situation. However, the key here is—and it goes back to what I just said to you about models—how do we determine what's a good pilot? A good pilot is not Tom Cruise in *Top Gun*. A good pilot is someone who understands the computer model better than anyone and can make the judgment about when he or she has to intervene. I think there's something to be said for that in terms of the statements as to what we should do going forward.

**Margaret Towle:** This has been a very, very insightful discussion, and we appreciate your taking the time to speak with us today.

**Robert Merton:** Well, thank you all. I hope you have found it useful. JIC

## Endnotes

1 In 1973, Fischer Black (1938–1995) and Myron Scholes (1941– ) published their option pricing theory, designed to calculate the value of an option by considering the stock price, strike price, expiration date, risk-free return, and the standard deviation of the stock's return. In a paper published simultaneously, Robert Merton introduced the principle of dynamic replication, making the theory more robust by showing it could be derived as a consequence of no-arbitrage instead of assuming the capital asset pricing model. He coined the term "Black-Scholes model." In 1997, Scholes and Merton received the Nobel Memorial Prize in Economic Sciences for their pioneering formula for the valuation of stock options. (Because the Nobel Prize is not awarded posthumously, Black, who died in 1995, was ineligible. However, the Nobel Prize committee noted Black as a key contributor to this work.) The Black-Scholes model, which represented a major contribution to the efficiency of the options and stock markets, remains one of the most widely used financial tools.

2 See http://www.nobelprize.org/nobel_prizes/economics/laureates/1997/merton-autobio.html.

3 Paul Samuelson (1915–2009) was an economist and the first American to win the Nobel Memorial Prize in Economic Sciences. Dr. Samuelson spent his career at the Massachusetts Institute of Technology, where he was instrumental in creating a world-renowned economics department by attracting other noted economists to join the faculty, including Robert Solow, Paul Krugman, Franco Modigliani, and Robert Merton, all of whom went on to win the Nobel Prize. Dr. Samuelson also was the author of the *top-selling economics textbook Economics: An Introductory Analysis*, first published in 1948 and currently in its nineteenth edition, having sold more than four million copies in forty languages.

4 Franco Modigliani (1918–2003) was an Italian-born American economist at the Massachusetts Institute of Technology Sloan School of Management and MIT's Economics Department. He was awarded the Nobel Memorial Prize in Economic Sciences in 1985 for his work on household savings and the dynamics of financial markets.

5 MIT Economics Department has a rule against hiring its own students, so this move permitted Merton to stay at MIT.

6 Robert K. Merton (1910–2003) was a distinguished American sociologist who taught for more than forty years at Columbia University, where he attained the rank of university professor, Columbia's highest academic rank. In 1994, the elder Merton won the National Medal of Science for founding the sociology of science and for his pioneering contributions to the field.

7 Functionalism, a major theoretical perspective in sociology, interprets each part of society in terms of how it contributes to the stability of the whole society. The different parts are primarily the institutions of society, each of which is organized to fill different needs and has consequences for the form and shape of society. Functionalism emphasizes the consensus and order that exist in society, focusing on social stability and shared public values; when one part of the system is dysfunctional, it affects all other parts and creates social problems, which leads to social change. The functionalist perspective achieved its greatest popularity among American sociologists in the 1940s and 1950s.

8 One of the economic theories pioneered by Franco Modigliani was the Lifecycle Hypothesis, which addressed individual consumption patterns during the phases of life, especially work and retirement years. Modigliani suggested that individuals plan their consumption and savings behavior over the long term with the goal of maintaining stable lifestyles. This theory proved useful in predicting the future effects of various pension plans.

9 The expected utility of an entity or aggregate economy is calculated by taking the weighted average of all possible outcomes, with weights assigned according to the probability that a particular event will occur. The expected utility theory posits that, under uncertainty, the weighted average of all possible levels of utility best represents the utility at any given point in time.

10 The mean-variance theory approaches risk and expected return mathematically by evaluating potential investments based on the expected value and variance of possible outcomes to find maximum return for minimum risk.

11 Dr. Merton served as a principal of Long-Term Capital Management (LTCM), a hedge fund established in 1994 that reached $7 billion under management by the end of 1997. The highly leveraged fund was designed to profit from combining academics' quantitative models with traders' market judgment and execution capabilities. In August 1998, following the Russian financial crisis and an ensuing flight to quality, the fund lost substantial amounts of capital and was on the brink of default. The threat of a systemic crisis in the global financial system led the Federal Reserve to orchestrate a $3.5-billion takeover by major U.S. banks and investment houses in September 1998. In December 1999, LTCM fully repaid the banks that had prevented its collapse. The fund closed in 2000.

12 In information technology, big data is a collection of datasets so large and complex that it becomes difficult to process using database management tools or traditional data processing applications.

13 The Pension Protection Act of 2006 was the most comprehensive reform of U.S. pension laws since the enactment of the Employee Retirement Income Security Act of 1974. It established new funding requirements for defined benefit pensions and included reforms affecting cash balance pension plans, defined contribution plans, and deferred compensation plans for executives and highly compensated employees.

14 Defaulters are employees who participate in employee benefit plans by default and contribute according to default investment allocations rather than making individual investment decisions.

15 The Pension Relief Act of 2010 provided retroactive pension funding relief for single-employer and multi-employer defined benefit pension plans that suffered significant losses in asset value due to the steep market slide in 2008.

16 Dale Gray, senior risk expert in the International Monetary Fund's monetary and capital markets department, has developed macro-financial risk frameworks linking finance, risk management, and macroeconomics. See Gray et al. (2006, 2007) for more on work discussed in this interview.

17 A Monte Carlo simulation is a sampling method that uses random numbers and probability to compute results, often used when a model is complex, nonlinear, or involves more than a few uncertain parameters. Monte Carlo analyses use inputs randomly generated from probability distributions to simulate the process of sampling from an actual population. The term is a reference to the games of chance popular in Monte Carlo.

18 A contingent claim is any financial asset in which the future payoff depends on the value of another asset. A common example of a contingent claim is an option, i.e., the right to buy or sell the underlying asset at a specified exercise price by a certain expiration date.

19 Dimensional Managed DC is a trademark of Dimensional Fund Advisors.

20 The capital asset pricing model (CAPM) is an economic model used to describe the relationship between risk (as represented by beta) and expected return. The CAPM was developed by William Sharpe in 1964 and others, building on earlier work by Harry Markowitz on diversification and modern portfolio theory.

21 Kenneth J. Arrow (1921– ) is an American economist and the Joan Kenney Professor of Economics and Professor of Operations Research, emeritus, at Stanford University. In 1972, together with Sir John Hicks, he won the Nobel Memorial Prize in Economic Sciences for his pioneering contributions to general equilibrium theory and welfare theory. See Arrow (1950, 1951).

22 Numéraire is a basic standard by which value is measured, or a unit of account. A numéraire is used to measure the worth of different goods, services, and assets relative to one another, i.e., in same units, to identify which goods, services, and assets are worth more than others.

23 This quote is attributed to British statistician George E. P. Box (1919– ), in his 1987 book with Norman R. Draper, *Empirical Model-Building and Response Surfaces* (Hoboken, NJ: John Wiley & Sons, Inc.), page 424.

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