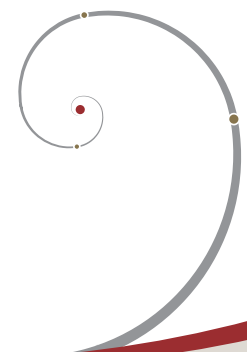


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Known as one of the primary architects of the Black-Scholes model, Myron S. Scholes applied his love of economic research to developing a fundamental tool of valuation that would become the standard in financial markets around the world. Together with fellow pioneers Fischer Black and Robert C. Merton, he laid the foundation that made the growth of the derivatives markets possible. The methodology behind the option pricing theory has been extended to provide the basis for the development of economic valuation in many other areas as well as the creation of new types of financial investments and opened new areas of research, both within and outside the field of economics. In 1997, Dr. Scholes' work was recognized, along with that of Robert Merton, with the Nobel Memorial Prize in Economic Sciences.

A native of Canada, Dr. Scholes earned his undergraduate degree in economics from McMaster University in Hamilton, Ontario, in 1962. He had become interested in economics at an early age, helping with family businesses and investing in the stock market while still in high school. At McMaster, he was introduced to the work of Milton Friedman and George Stigler, both of whom then were teaching at The University of Chicago. Inspired by what he read, he decided to pursue graduate studies in economics at The University of Chicago, receiving his MBA in 1964 and his PhD in 1969. After completing his doctoral dissertation, Dr. Scholes joined the faculty of the Massachusetts Institute of Technology's Sloan School of Management as a professor of finance. It was there that he would meet Fischer Black, then a consultant with Arthur D. Little in Cambridge, and Robert Merton, who joined MIT in 1970. The three men became interested in research into asset pricing and derivative pricing models, which eventually led to the groundbreaking 1973 article on option pricing theory that established the Black-Scholes model.

In 1973, Dr. Scholes returned to The University of Chicago, taking a teaching position at the Graduate School of Business and continuing his research, working with Merton Miller, Eugene Fama, and Robert Hamada, among others. While at The University of Chicago, Dr. Scholes also worked closely with the Center for Research in Security Prices, helping to develop its comprehensive research database of historical stock market data. In 1981, Dr. Scholes left Chicago for Stanford University,



Myron S. Scholes, PhD

where he remained until he retired from teaching in 1996 as the Frank E. Buck Professor of Finance, Emeritus, at the Stanford Graduate School of Business. He also held the position of senior research fellow at the Hoover Institution from 1987 to 1996. While still at Stanford, Dr. Scholes became interested in applying his research into derivatives to the real-world business of financial intermediation, becoming a special consultant to Salomon Brothers in 1990 and then managing director. From 1994 to 2000, he was a principal and limited partner at Long-Term Capital Management. Dr. Scholes currently serves as the chairman of Platinum Grove Asset Management, a hedge fund he co-founded in 1999, which is based in Rye Brook, NY. He also is a member of the board of directors for Dimensional Fund Advisors.

Over the years, Dr. Scholes has written numerous articles for professional journals and contributed to many books, focusing on topics including the effects of taxation on asset prices and incentives, taxation and capital structure issues, investment banking and incentives, and the interaction and evolution of markets and financial institutions. He is the author (with Mark Wolfson) of *Taxes and Business Strategies: A Planning Approach*, which examines tax planning under uncertainty and information asymmetry. Dr. Scholes has been awarded honorary doctorate degrees by the University of Paris-Dauphine (1989), McMaster University (1990), Katholieke Universiteit Leuven (1998), and Wilfrid Laurier (2005) as well as an honorary professorship at Nanjing University (2009).

In late October 2009, Dr. Scholes spoke with members of the *Journal of Investment Consulting's* Editorial Advisory Board about his love of economics and economic research, his thoughts about dealing with crisis and regulation in the markets, and expanding roles for advisors and consultants in the future. Taking part in the discussion were Margaret Towle, the *Journal's* editor-in-chief, of Greycourt & Co., Portland, OR; Mark Anson of Oak Hill Investments, Menlo Park, CA; Edward Baker of The Cambridge Strategy, London, UK; Geoffrey Gerber of TWIN Capital Management, McMurray, PA; and Meir Statman of Santa Clara University, CA. This interview is the ninth in the *Journal's* Masters Series, which presents topical discussions with leading experts and visionaries in finance, economics, and investments.

Margaret Towle: Dr. Scholes, your career has been absolutely extraordinary, including the Nobel Memorial Prize in 1997 and your academic career with the influences of Milton Friedman,¹ Merton Miller,² and others. In turn, you've influenced the lives of so many, in terms of the research you've done, in teaching, and so forth. We are especially interested in the factors that helped to shape your career and bring you to where you are today. Perhaps you could also talk about what you consider your biggest achievement and your biggest mistake.

“ My major achievement has been a body of research, not the least of which is the crown jewel, which is the option pricing theory³ and its applications. ”

Myron Scholes: Actually, what shaped my career was a little bit of luck and a little bit of skill. I intuitively came to the conclusion that I should try to go to school where the best people were, because I would be able to steal as much as I needed from them, or as much as I could. That led me to The University of Chicago. I realized that I would have to be good myself to keep up with the people there, because if you are with the best, you have to try to be the best yourself. I was then fortunate enough to become a computer programmer at The University of Chicago at a time when virtually no one knew what a computer did, or how to program one. I provided programming assistance to a number of professors and fell in love with their enthusiasm for their research. As a result, I decided that this is a wonderful area, a wonderful experience. I went on to get my PhD, and I fell in love with research and ideas. The rest is history.

One of the things that shaped my career, and continues to shape my career to this day, is my love of the combination of theory and experience. I've always felt that theory alone—without experience—is not very valuable, and the converse is also true. Just experience, or being experiential without putting a framework around it, also is not valuable. I've always loved the idea of learning the details, trying to understand in depth what I need to know, and then trying to conceptually think about how all of the pieces fit together. I figured out a long while ago, and still use to this day, the fact that you have to gather data—you have to be inductive and gather data—but you have to make the decision to stop and then deduce something important and sustainable from the data you've accumulated. It's fun to do that, and I've enjoyed it.

I think, as you said in the introduction, that my major achievement has been a body of research, not the least of

which is the crown jewel, which is the option pricing theory³ and its applications. This research has had a great effect on others, and they have used it to extend their thinking, their understanding, and their applications of research to practice and theory. Also, for those who didn't like parts of my research, it led them to go in different directions and make new discoveries. I think the biggest mistake or disappointment was when I was in practice with Long-Term Capital Management.⁴ Although I was a partner, I relied too heavily on others for the risk control piece. If I had taken a more proactive role, as opposed to a more consultative role, then I may have been able to step in earlier to reduce risk. That was, if you want to characterize it as such, a major disappointment.

Meir Statman: Speaking of academia and practice, I can see the link between theory and practice, but as enmeshed as you now are in practice, do you miss academia? Does it seem that the work in the field is as exciting in the trenches as in academia, or do you get bogged down with administrative details and so forth that you could have avoided in academia?

Myron Scholes: Well, I wish that were true in academia. I found that academics seem to have a lot of time on their hands and argue about the smallest points. I spent a lot of time grading papers, working with students on their particular problems, handling administrative duties, committees, etc., etc. There's considerable work that an academic has to do. It's not all ivory tower, where you can sit and think big thoughts and teach lectures. There's a lot of administrative work to academics as well. Even in running a business, it's necessary to know how to delegate responsibility and at the same time build systems that provide feedback mechanisms to check what's going on. I always believe in incentives, but I also very much believe in measurement and using that measurement as a control mechanism. It's been fun to do that. It's also been fun for me to learn how to lead an organization and to lead other people. That has been a great experience. I have learned a lot about leadership.

Obviously, I'm not completely divorced from academics. I think I now give more lectures and talks to more people in a formal setting than I did when I was a professor. What I don't do enough of now, in a relative sense, is write up my ideas, because it's tougher for me to get the time to do that. I do miss things about academia—the idea generation, the discussions, and the vibrancy of the students. When you leave an activity, at the margin you are rather indifferent, because if you knew that you wanted to leave that activity for sure, then why would you have waited so long to do so? I think it's always hard to leave, but at times in your life it's necessary to repot yourself and challenge yourself. I wanted to learn about the financial intermediation business, and I couldn't learn about that from reading textbooks and articles or while being outside the business. I really had to think about it from the inside, and that has been a good learning experience for me.

Ed Baker: I remember when I first learned about the option pricing model many years ago when I was a student. I was very impressed by the thinking behind that. When you

did that work, did you have any idea how important it would become?

Myron Scholes: No, we always thought that it would be applicable to existing contracts such as call options or warrants or corporate bonds. I never thought that others would take the technology and the intuition behind the option pricing theory and build new products and conduct new research or use it in ways that were far afield from our original thinking. It was really exciting for me to watch those developments. I mean, for example, I never thought of real options as a research field.

Meir Statman: I think the option pricing model and options, or derivatives more generally, have been used for good. However, covered calls continue to be advertised as free lunches. You railed against that as far back as an article you wrote in 1978 (Merton, Scholes, and Gladstein 1978). Do you see cases where options are being used to obscure? Of course, we cannot think about the market events of the past couple of years without thinking about the role of derivatives in what happened. The real question is whether people, even the people who designed those derivatives—the credit default swaps and the like—understood themselves what was involved, let alone could explain it to people who were not as immersed in derivatives as they were.

Myron Scholes: Well, yes. Science might not be applied correctly. Obviously, appliers of technology can apply it incorrectly or obscure benefits and costs. For example, Porsche designed a highly efficient and powerful car. Drivers who don't know how to drive it, however, might have many accidents. I think we believe that there is value in using technology and ideas, and we understand that mistakes will be made. If everyone knew exactly which way to go and what was the correct way to apply technology, it already would have been done or we would find that it is boring and find new applications. Your question is a broad one. The first part involves investors who make mistakes using covered call options to generate extra income, forgetting that they lose if stocks fall in price (and giving up on the upside as well). There are no excess returns to be made in call-selling strategy unless the calls that are sold are overvalued. I agree with you. And, the mistake in believing that call-selling strategies provide excess returns is common in many different investment activities. For example, floor traders on the options exchanges might sell options to generate income, or investors might sell other forms of embedded options in financial contracts thinking they're garnering extra income such as buying high-yielding products. High-yielding products have risk of loss as clearly shown during the recent financial crisis. Take for example, the ubiquitous "money market fund" or "bank deposit." Although money market funds invested in higher-yielding paper to garner extra current yields for investors, they promised their investors that they would always receive one dollar back for each of their shares. But that was an impossible promise to keep unless the government stepped into their shoes and guaranteed the investments. The call-writing strategy is prev-

alent in one form or another across the investment spectrum. The problem is offering stable value products that provide higher income most of the time but can't really guarantee that investors will receive their principal back. Those who run the money market funds are knowledgeable and aware of this problem; they feel, however, that investors want the illusion of stable value or maybe they believe that the government will provide the option protection, if needed. Similarly, insurance companies offer stable value products such as annuities that promise investors they'll at least get their money back plus a 2-percent or 3-percent minimum return. At the same time, however, the insurance companies invest investor proceeds in higher-yielding bonds or equities to provide extra returns most of the time; at other times they have gone broke as markets moved dramatically against them—for example, Equitable or AIG. There are myriad cases where investors, or even institutional managers, sell options, creating seemingly higher returns for their investors while guaranteeing principal, and as a result worry—or maybe don't worry—about the consequences of an investment defaulting and having to take losses on the initial investment. The same is true of investment banks and banks. They earn higher current income on holding illiquid inventory. They report higher earnings to shareholders as long as they don't need to liquidate this inventory. From time to time, maybe during a crisis, they are forced to liquidate this illiquid inventory to reduce debt and risk at a large loss. They can't guarantee the principal of their shareholders. All of these are equivalent to our discussion on call-writing strategies; all of these products have options embedded in them. Now, all of these faults existed before the Black-Scholes model. They existed in myriad forms. And, our research points to these faults and how to correct and understand them.

Meir Statman: I'm surely not going to fault the Black-Scholes model. However, using your current example of an automobile, we have speed limits on the highway, rather than leaving that up to the drivers. I was just wondering what you think about the role of government regulation and to what extent government should stay out of things and leave it to the market? Or is there a role for government in saying, for example, whether money market funds where prices are not marked to market should be prohibited?

Myron Scholes: That is an excellent question. I don't think that we should prohibit money market funds. Although we know that speed limits don't work all of the time, society does believe that they constrain speeding and reduce the external costs caused by these accidents. Is it better to prohibit money market funds, or is it better to allow them, and, therefore, occasionally society will have to step in and guarantee their net asset values? I believe that we should restrict "excess speeding" and police it. We must decide, however, how to put meat on the bones. Up until now, we've taken the view that if banks fail, we bail them out. I believe that we shouldn't bail out the debt holders. They have to bear the risks. If they do, bond yields will reflect this and

constrain bank risk-taking activities. And, we must decide on what constraints to impose on bank activities and capital that will not destroy the productivity of our society and will not prevent any bank failures, etc., but will limit the costs of systemic failures on society. We must find the proper balance. I think that's a societal decision—at the extreme whether to be proactive or just reactive to each crisis.

Mark Anson: To build on Meir's question for a moment, one proposal has been to have a central clearinghouse for over-the-counter contracts: options, swaps, and other derivatives. I'm not certain it's feasible, but just in general, without trying to pin you down, what are your views on that?

Myron Scholes: For all contracts that can be moved to a central clearing corporation, I think that idea obviously has a lot of benefits, for the cost of clean-up of all of the existing bilateral contracts is reduced dramatically. Right now, if a hedge fund or another entity wants to unwind its obligation, it needs to negotiate with the entity from which it undertook the contract. The cost of doing so, however, might be greater than entering into an offsetting contract with another entity. As a result of all of these offsets and the cost of eliminating outstanding contracts, the notional amount of derivative contracts grows dramatically. And, at times of crisis, the clearing corporation can offset contracts and eliminate counterparty uncertainty and risk efficiently since all contracts are effectively back-to-backed with a clearing corporation. (For example, theoretically, if Lehman had back-to-backed its over 2 million contracts with a clearing corporation, on its bankruptcy all of its contracts could have been netted and closed efficiently at mid-market pricing, reducing the dead-weight settlement costs and risks associated with default.) So I think that would be a great benefit to allow for a way for contracts to settle efficiently, especially in times of crisis.

On the other hand, the issue is to what extent and how many contracts can be migrated to exchanges or clearing corporations and how that should be done, because clearing corporations don't want to go broke themselves. Therefore they need to understand the underlying contracts, and they don't have the skills to understand idiosyncratic or complicated contracts. To date, only standard-form contracts have been cleared on clearing corporations or options exchange clearing corporations. And, these contracts settle each night since as values change entities post more collateral. Over-the-counter derivatives don't have readily observable market prices. A clearing corporation will not know how much collateral to demand at the end of the day to protect itself on other than standard-form contracts. And, during the crisis interest-rate swaps were not the problem. Other hard-to-understand structured products that are difficult if not impossible to clear were the difficulty. As we see, if we constrain activities such that all contracts need to be cleared on clearing corporations, the number of innovations, experiments, and idiosyncratic solutions for clients would be eliminated. Maybe others would claim that to be beneficial, but I've always thought that the intermediation process had value for society, in part,

because it handles specifically what the customer needed by fashioning idiosyncratic solutions for the client. As these solutions become standard, they could be cleared.

Since a clearing corporation is a separate legal entity, users would worry about all of the cross-margining problems that exist among contracts that might be cleared with the clearing corporation that are hedged by using swaps or other derivative contracts that are not cleared there. The actual margin required to post with each entity might far exceed the theoretical margin; that is, the margin that is actually necessary to assure performance if all contracts were cleared on one platform. This extra margin might make the clearing corporation prohibitively expensive for users needing to post excess collateral because their borrowing costs might far exceed the rate paid on collateral at the clearing corporation.

“As we see, if we constrain activities such that all contracts need to be cleared on clearing corporations, the number of innovations, experiments, and idiosyncratic solutions for clients would be eliminated.”

We must start on the details of over-the-counter derivatives. Overall, I would say yes to the idea of clearing corporations but there are major difficulties that I think should be solved prior to its implementation. That is, in bankruptcy, how do these over-the-counter contracts settle? Even today, the Lehman Brothers estate has 1.5 million outstanding contracts that have not settled or unwound. When Lehman went bankrupt,⁵ the firm had something like \$21 billion of asset value and \$15 billion of liabilities in its derivatives program. The \$21 billion has shrunk to only \$4 billion, while its liabilities have shot up from \$15 billion to approximately \$100 billion. This has been caused by the time delay, lack of understanding of the contracts, and the lack of incentives to conserve value. It's in the details. The bankruptcy mechanism is really the main issue; it imposes the bigger cost on the financial system and creates the most uncertainty. Regulators and practitioners should figure out how to make the system more efficient. I have argued that at the default of either a clearing corporation or a bank, all contracts are unwound at mid-market terminations within a period of three to five days. Entities would be able to recontract with nonbankrupt entities. In addition, mid-market settlement would greatly reduce the need for collateral and reduce cross-margining costs.

On the other hand, without mechanistic redesign, a clearing corporation bankruptcy would create another mess.

Ed Baker: Taking a more academic point of view, I'm thinking again that when I studied Black-Scholes, I was impressed by the power of the no riskless arbitrage principle in finance, which was part of the beauty of the whole derivation. I wondered how important you think that principle is broadly and why it doesn't get more attention? How important is it for markets to allow mechanisms that push in that direction?

Myron Scholes: You are correct. I used that principle even in my doctoral thesis forty years ago, in which I introduced the theory of substitution versus flows in financial markets into the academic literature. If assets with similar risk-return characteristics are priced differently, then intermediaries have an incentive to close the market and bring the prices back into line. As you point out, in the Black-Scholes world, the option and the underlying security were perfect substitutes. Substitution versus flows is the primary trade-off that all intermediaries face. Markets function because intermediaries assess values and buy assets that they think are cheap relative to other assets that they sell to hedge their risks, believing that substitution will bring security prices back into line. If flows, however, overwhelm substitution, intermediaries might not be able to hold their positions long enough or worry that they no longer understand valuation. Finance compresses time. If an investor wants to buy something today and there's not a ready seller for it, an intermediary steps in to provide it until the seller comes forward. However, the intermediary can't intermediate unless he believes in a valuation to supply the inventory outright or he can hedge and reduce its risk and show either through arbitrage or through hedging that he was correct in his valuation. In the press and in academic circles there is the belief that the Black-Scholes technology was developed using the concepts of efficient markets. It was not based on efficient markets.

Ed Baker: No, not at all. It was based on arbitrage pricing theories.

Myron Scholes: That's correct—on the idea that if a derivative and its underlying security are perfect substitutes, then one can be priced relative to the other and the expected return does not play a role in the formulation. Efficient markets says something about the mean and the process underlying the evolution of the returns from equilibrium values (for example, not mean reverting or trend following); option prices have something to say about volatility and nothing to say about the mean. I think this idea of arbitrage, or hedging or risk management, is a primary part of financial markets and how markets become efficient.

Ed Baker: I do, too, and I've never understood why the financial community doesn't put that principle up as *the* most important principle in finance.

Myron Scholes: Thank you. I appreciate that. Others might dispute that, but I'll accept it.

Geoff Gerber: You've talked about measuring risk, and you've talked about bank failures. You've also been quoted as

saying that while any one bank can measure its risk, the real problem is that it also has to know what risks are being taken by other banks in the system at any particular point in time. How would they go about that?

Myron Scholes: To me, that may be the key role of the proposed systemic risk regulator.⁶ I worry that the systemic risk regulator will by necessity have to figure out where asset bubbles are at any moment, and that's an extremely difficult task for anyone. Where are the asset bubbles now in the system? And, there are so many that naturally arise and disappear without consequence.

Margaret Towle: I love your terminology—the Fed.com bubble. That's great.

“ We don't want to observe a future scenario wherein the systemic risk regulator can't find any asset bubbles over a period of time, and, as a result, investors and institutions take more risk. ”

Myron Scholes: Well, thank you. We don't want to observe a future scenario wherein the systemic risk regulator can't find any asset bubbles over a period of time, and, as a result, investors and institutions take more risk. To follow on from the risk aggregation question more directly, the systemic-risk regulator should aggregate risks of the various banking institutions and maybe hedge funds and others in the so-called “shadow-banking system” and disseminate the risks (short-term risks, the so-called “greeks,” and scenario risks, etc.) to the financial community in aggregated form. The financial community will be able to adjust its own model assumptions and its own risks more efficiently on learning about the aggregated risks in the system and, in my view, act to reduce systemic risk in the system.

Geoff Gerber: You bring up hedge funds, and obviously hedge funds in 2008 were a major disappointment at one level because, contrary perhaps to some investors' priors, they did have a beta component. What do you think about hedging strategies going forward?

Myron Scholes: Beta theory is incomplete. It was developed under the assumption that investors liquidate and reconstruct their portfolios at the end of each period without cost. And, the opportunity set is assumed to remain unchanged to measure beta and performance using historical data. I think there are at least two functions that generate the returns on securities. One is an evolutionary process, wherein returns are created by generating factors and idiosyncratic

risks. Hedge funds can hedge factor risks and create zero-beta portfolios. The second function is a liquidity process. Since at least 2000, in papers I've written and talks I've given—at times of liquidity shocks, or when all intermediaries stop intermediating because they can no longer calibrate their models or assess valuations correctly, asset prices that appeared to be uncorrelated most of the time become highly correlated. I have called the provision of liquidity and risk-transfer services, “Omega.” Most hedge funds and alternative investors earn returns by providing Omega services. They earn returns by buying less-liquid assets and those assets that investors do not want to hold at a particular time. They hold these assets until they are able to liquidate them when Omega prices change in their favor. In 2007–2009, Omega providers lost as asset classes fell in value—even though they had a zero beta in a classical sense—as all asset classes seemed to move together since Omega prices moved against them. As a result, measured correlations increase. Stocks fall, bond prices increase, interest rate curves steepen, and volatility increases as flows caused by investors wanting to convert to cash to reduce risk overwhelm substitution until intermediaries have time to recalibrate their models and to discern new valuations. As a result measured betas increase dramatically.

Basically, I think that at the time of a shock like we had on different occasions over 2007–2008, and, in particular, at the time of the Lehman failure and the aftermath thereof, everyone was trying to reduce risk and liquidate, and the market intermediation process stopped. In finance volatility and time are the same. When markets are quiet, everyone has more time to think and more time to act, and it takes longer for things to evolve or to change by very much. As volatility increases, however, market participants are forced to act more quickly. When volatility becomes extreme, time stops. With large shocks, volatility becomes extreme because so many decisions have to be made quickly and without an ability to evaluate and incorporate all of the information available. As a result, intermediaries withdraw capital and reduce their Omega provision in markets. I call that the “Heisenberg uncertainty principle of finance,”⁷ because, as soon as investors no longer know value or liquidity needs or who's selling, (their fixed point), the flows (velocity) overwhelm the power of substitution. At that moment, two things happen: liquidity dies and asset prices jump. Market participants need time to reestablish value and separate price movements attributable to value and liquidity price changes. That functionality produces a very high measured beta, but it's not the beta of the Sharpe capital asset pricing model sense,⁸ or the market model sense. The market model assumes draws from the same urn. Mixing market model evolutionary process returns with those of a liquidity process generates distributions that have fatter tails.⁹ So it's liquidity in the intermediation business that really needs to be understood going forward. I think a great direction for future research is to understand the value of liquidity, ways to measure it, and the implications for society, as well as why the intermediation business fails and what

we can do to mitigate failure, if anything. Providing liquidity and risk transfer has been a service provided by hedge funds and other intermediaries in the past. If we do not allow banks to do so in the future, who will provide the intermediation function so important to making markets efficient?

Ed Baker: There are some new techniques being developed for managing risk when you do have fat tails. Have you looked at that literature at all, and do you have any comments?

Myron Scholes: I have read the extreme value theory literature. There are others who assume that fat-tailed distributions can be used to model risk in the extreme. Most of these approaches, however, use reduced-form marginal distributions without trying to understand and model the underlying economics. That is why I and others are trying to model and understand the intermediation process and when and why it breaks down. When it breaks down, we observe extreme price movements and although we are unable to predict when these will occur, we are able to predict their direction and magnitude. We know that liquidity is akin to a put option. We don't know, however, the form of the option necessary to protect us at times of shock. That is why the degree of flexibility in operating and financing policies is a business decision at the option of management. For example, we know that with shock asset values fall and to reduce risk banks must sell assets or issue equity to reduce risk. If banks issue equity, however, the lion's share of the benefit is transferred to its debt holders because the extra equity protects them against default. As a result, banks are forced to liquidate assets to reduce risk and to do so in an illiquid market wherein value and liquidity needs are difficult to discern quickly enough. Leverage is akin to cancer in the sense that it is necessary to do something to get rid of it. There are more efficient ways to rid banks of their debt cancer than having taxpayers bail them out. We have to figure out automatic ways to rid us of that cancer. For example, if the debt of financial institutions converted into a certain fraction of the equity of the firm at the time of a systemic event, it would give intermediaries time to recalibrate their models, to revalue assets, and to make new flexibility decisions without needing government intervention or a wholesale liquidation of assets at fire-sale prices. This forced conversion would mean that we would not need governments to bail out financial institutions; they would bail themselves out. And, if debt holders suffer loss, they would be more cautious and, as a result, reduce the possible magnitude of a crisis.

Ed Baker: That would certainly change the game for the stockholders. Presumably that would impose a greater standard of governance and risk measurement on the part of management.

Myron Scholes: That's right. Why not? That goes back to my earlier point. Society has a choice: Should we be reactive and pay the price after the crisis? Or do we think of measures that are proactive, and the price is paid over time, and, as a result, build more flexibility into our financing decisions? Our

decision to date has been to bail out institutions. Over time these decisions have increased moral-hazard problems. The recent collapse of our financial system and resultant bailouts has led to anger and calls for the “heads” of the bankers and could lead to extreme constraints on their activities. Perhaps now is the time to be proactive and make changes in advance that will constrain activities but allow market participants to make choices. We might not be able to write rules that prevent crisis. We can, however, change contractual forms to protect society in the event of a shock. We have to think of mechanisms that are self-correcting, as opposed to trying to regulate the rules of the road. I agree with Meir that we need speed limits in place, in the sense that banks need additional capital that would reduce leverage. However, leverage is only one part of the speed-limit constraints. Banks can reduce flexibility not only by using a lot more leverage but also in many other ways, such as concentrating very heavily in one activity (such as Lehman’s illiquid real estate investments), or reducing bonds in their portfolios or cash reserves (as Bear Stearns), or selling off businesses that are cash-cow businesses and then investing in growth activities. Even after restricting leverage, there are myriad ways that banks and other intermediaries can reduce flexibility in the system. This needs study and the cooperation of academics and practitioners.

Ed Baker: In part it’s a matter of asymmetric incentives on the part of the management. They do well when the risks pay off, and they aren’t really hurt that much when the risks don’t pay off.

Myron Scholes: That’s correct. There is the “trader” model or the “investor” model. The trader model is one in which the trader says to the boss, “I don’t need very much capital to run my business because I’m hedged, I have no beta risk, I just have pure profits ahead of me.” And the boss says, “No, you need capital because you’re not going to be right 100 percent of the time, nor are you going to be right immediately.” Traders want as little capital allocated to them as they can possibly get away with for they realize high returns on capital and are paid well accordingly, most of the time. When a shock occurs, however, the trader loses money and runs to the boss and says, “My opportunities are the best I’ve ever seen, but I need more capital because I am broke.” Heads traders win; tails the firm losses. If I leave home and I carry my umbrella—thereby creating flexibility—and it doesn’t rain, then I’ve paid the price—I’ve carried the umbrella. On the other hand, if I leave the house without the umbrella and it does rain, I have to scurry around New York City to find an umbrella on a street corner, or I get wet. So there’s a trade-off. Flexibility—both financing and operating flexibility—is a business decision. I think the trader model tends to move toward “Let me be reactive; I need little capital because I am hedged, and I am able to make more money if I don’t provide for the possibility that I will need more capital at times of shock.” The investor model requires that managers have enough capital to sustain their positions at times of shock.

There is no “boss” to call at that time for extra capital.

Mark Anson: So let’s say you walk out of your house without your umbrella, it rains, and you have to buy an umbrella on the street, but now you’re going to have to pay a premium to buy that umbrella on the street. So you still have to pay for that optionality one way or the other.

Myron Scholes: You’re right. That it is why it is a business decision. If bankers come to the conclusion that shocks are unlikely or that carrying the extra capital is too much of a drag on reported earnings, they prefer to be reactive, and, if needed, buy the umbrella on the street corner. That’s a business decision. And, it might be easier to make that decision with the possibility of a government bailout. For example, a venture capitalist might invest in a start-up that needs \$10 million in expectation of finishing research and development and marketing the project before the start-up becomes self-sufficient. However, six months later we often hear: “Things are going great, but we need more capital.” To make the correct investment decision, the flexibility option has to be valued before the fact and added to the direct cost of making an investment, to compute the correct return on capital; maybe the correct investment is not \$10 million but \$15 million. If too little capital is allocated to a project, investors, bank management, and others cannot make the correct allocation decisions. We need to learn how to make dynamic adjustments. This is the future for bank (and other) investment allocation decisions.

Endowment funds, for example, in recent years decided that they did not need a reserve against shocks or liquidity crises. They reduced their bond holdings to maybe 3 percent of their portfolios. Why? They felt that their time horizon was very long and that they did not need flexibility in their investment allocations. This turned out to be incorrect. Or pension funds have invested a large fraction of their portfolios in equities. Why? Because they have a long horizon and equities are nearly certain to outperform bonds over a long horizon. The problem, however, is that although in expectation stocks outperform bonds over a long horizon, the longer the horizon the greater the possibility of a shortfall when the money is needed to pay beneficiaries. The value of a chooser option, the maximum of stocks or bonds over a thirty-year horizon might represent 40 percent of the value of the portfolio. Once again, volatility, optionality, or the value of flexibility must be part of the investment decision-making process. And, adding to the problem—and I’m responsible for it as are others—is that we assume that the world is putty-clay-putty.¹⁰ Investors start with putty today, make investment decisions, putty into clay, and at the end of the investment period, convert clay back into putty, and start over again without cost. But, the world does not work that way. At times of shock, for example, converting illiquid assets to cash to build flexibility is very expensive. Finding an umbrella in a rain storm might be impossible or very costly.

Margaret Towle: Could we switch gears a little bit and go back to something you said earlier that I found interesting?

“ **Consultants and intermediaries are extremely important, and even more so as the number and complexity of investment choices have increased over the years.** ”

You said that you really love the combination of theory and experience. I know that you’ve recently spoken on some contemporary topics such as the rally in junk companies and the metrics that people are using to measure that. Are there ideas about looking at what’s currently going on in the markets that are well-known or understood by professionals, but not by individuals?

Myron Scholes: Yes, certainly. By definition we’ve had myriad managers who are trying to make money by understanding the complexities of various arrangements that are impossible for individuals to do on their own. For example, how does the typical investor value Lehman bonds or their outstanding other claims? No one can do that without diving into it and spending the countless hours necessary to try to figure out and understand all of the game-theoretic approaches to value those instruments. The same thing is true in many other instances in finance. Division of labor is very important. Markets become efficient or move toward efficiency because of individuals who are willing to take the time to actually evaluate situations and to act on those evaluations because they believe they have found opportunities that will earn them money for the capital they need to employ and the time necessary to hold assets before realizing returns.

Margaret Towle: I was thinking of my question in the context of a large part of the audience for this publication, that is, investment consultants, in terms of their role with institutional clients and individual investor clients.

Myron Scholes: Consultants and intermediaries are extremely important, and even more so as the number and complexity of investment choices have increased over the years. In the investment world, we know that an index fund (or equivalent) has the lowest costs and also the lowest monitoring costs. It’s very easy to measure the shortfall from what an index fund alternative might be. If one invests in a hedge fund, which doesn’t take factor exposures, the monitoring costs are much greater. Intermediaries are needed to help investors decide among all the alternative hedge funds and the myriad alternative investment vehicles. And, consultants and advisors are necessary to plan for liquidity needs and asset allocation decisions. Clients are moving to wanting investment solutions.

The interesting evolution in finance that we’ve seen over the last forty years or so is a movement in responsibility down to individuals to make investment decisions and away from

governments and corporations. In the past, individuals were not very heavily involved in the stock market. For their retirement and savings, they relied on their defined benefit pension plans, their homes, and to some extent Social Security. But, without choice, individuals had limited flexibility in their retirement savings programs.

The analogy I like to use is that when I was young, we had a radio in our home, and it was a big box—all of those woofers and tweeters and so forth were right in that big box. Later on, I could buy components and put together my own system. The same thing has happened in the investment world. We left the world of the big-box solution and we forced individuals to make all of the decisions about ways to allocate savings, saving for the education of their children, saving for retirement, saving for healthcare, life insurance, health insurance, living too long, dying too soon, risk tolerance, human capital, etc. We can’t make all of these decisions ourselves—we need advisors and consultants that help us put all of this together. Their advice is very valuable and will continue to be so. Their importance continues to grow because making these decisions will become more complicated; we need their expertise to figure out how to put the components together to make the system work.

We’ve moved to the next steps in the stereo component world. A few years ago, when I wanted to put a new system into my home, my stereo person told me that he’d come to the house and discuss what I wanted in my new system. Although I asked him about specific component parts, he told me to forget about that. That was his job. He wanted to know my tastes in music, television, etc. When it was completed, I had a media center. It was the box I had as a kid, but it was my own box now, not that “one size fits all” system, but one designed just for me. That will happen with investment programs in the future. An advisor will analyze client needs and then design solutions, or media centers, that suit that client’s needs. Now, obviously, the media center was a reconstructed radio; the stereo person took the components and built a better system for me. A year or so later, I wanted to buy an iPod, and it didn’t fit into my media center, so solutions deconstruct and reconstruct over time. Note that the difference here is that the components of the media center are less important than their output. The same will become true of investments. And, depending on adjustment costs, the program will be flexible because with volatility we keep learning and our tastes change. It takes technology, know-how, experience, and methods to understand client needs and how those needs can be satisfied. Clients don’t have the ability to do so on their own.

Margaret Towle: That goes back to some of the ideas of financial innovation. In October 2009, you spoke at Pace University.¹¹ I didn’t hear the talk, but I believe you were defending contemporary financial innovations.

Myron Scholes: I had not wanted that talk to be a debate about financial innovation; I was very much against a format that required that I defend financial innovation. Debaters point to individual events to try to prove that innovation is

costly, which I agree it is. We know that innovation must lead infrastructure that monitors and controls innovation. And, we know some innovations fail. However, when the benefits of innovation are diffused across a spectrum of activities, it is difficult to marry all those benefits together to compute the total value, especially when one can point to individual instances of failure or specific instances of great cost. One of the reasons the Securities and Exchange Commission was put into place in 1934 was that during the hearings following the stock market crash of 1929, regulators heard from a parade of individuals talking about specific instances wherein people had been hurt by investment advisors. It is hard to argue against failures. On net, I claim that successful innovations survive the test of time. And, we have had myriad financial innovations in that category. Even credit-default swap contracts, such as those that brought down AIG, have survived and provide valuable credit-pricing signals and hedging instruments.

Margaret Towle: Speaking of innovations, and we've touched a bit on this already, can you give us some of your thoughts about major trends in the investment industry today, specifically those that you think will still be around in five years, or twenty years?

“ I think we're going to see more and more of a movement to customized solutions for investors, where advisors play a more and more important role. In addition, intermediaries will work to devise products that satisfy client needs and do so in a way that is more service-oriented or client-oriented. ”

Myron Scholes: I think we're going to see more and more of a movement to customized solutions for investors, where advisors play a more and more important role. In addition, intermediaries will work to devise products that satisfy client needs and do so in a way that is more service-oriented or client-oriented. Individuals think in terms of activities. They think about transacting, about saving for the future, about investing in large projects, about risk management, etc. Entities tend to think in terms of products, that is, a growth fund or a high-yield product. The growth area in the investment future is to put the client's wants first and then work to figure how technology—whether it's computing or telecommunications or financial or a combination of all of

these—can help satisfy the client's demands. To me, that must be a growth industry because it's very confusing for individuals or even entities to figure out all of this on their own. We're in a world of second best,¹² and we have to realize that's the case. In the world of second best, advice is valuable and investors are willing to pay for it. It's not just return-based; that is, informing the client that he can make the most by investing here, or investing there. It's really much more than that; it is understanding the client's horizon, liquidity needs, other contingencies, risk tolerance, human capital constraints, and other wants that have to be satisfied and figuring ways to achieve the desired program.

Meir Statman: If I might use a medical analogy, physicians are paid by procedure. The doctors who provide the advice that you are talking about are general practitioners, and generally they are not paid very well. I see the same problem in the financial advisory community, where investors are not willing to pay for advice. They are willing to pay for products, for procedures. How can individual investors be persuaded to understand that the real service they get is that integration you talked about, rather than whatever product is going to beat the market, and be willing to pay accordingly?

Myron Scholes: You're right. It will be tough to change the psyche. But, benefit wins out. As a follow on from your analogy, I'm a very big proponent of holistic procedures to health management, wherein exercise, diet, meditation, vitamins, and supplements are as crucial as tactical approaches. It's hard to move to this proactive approach because it's harder to make money providing such advice. In medicine, to use your analogy, if doctors can be educated and come to believe the advantages and are able to advise their clients on the idea of the right types of vitamins, for example, and clients themselves come to realize the benefits, they will pay doctors for the service. For example, I pay a doctor an annual retainer to give me nonspecific advice. The problem now is that the drug and device companies provide information to doctors, and doctors don't necessarily have alternative low-cost information sources on other approaches. So, essentially there's currently no educational clearing mechanism to keep the doctors informed. With technology and the advent of information systems, information on alternative methods will become readily available. It's a transaction cost problem, and the same is true for the financial advice business. If the transaction costs fall because of information technology, and financial technology makes it easier and less expensive to take the total package advice approach, as opposed to selling individual components, we'll see an evolution in that direction. In my opinion, costs will fall and learning will accelerate.

Ed Baker: We already touched on the recent economic crisis, but if you had to point to one important lesson that you learned from this, what would you say?

Myron Scholes: We don't know the riskiness of the state of the world in which we live. It seems that in recent years we had come to the conclusion that risk had been permanently reduced. And, this turned out to be incorrect. Over time we

became convinced that the economy was under control. We must realize that it is difficult to know whether the recent period is the best indicator of the future. How do we know the real state of the global economy? Macroeconomists told us that they could dampen business cycles, the so-called “great moderation.” We learned that Mr. [Alan] Greenspan¹³ and others claimed that risk transfer dampened the effects of shocks. And with the shocks of the recent past, we were told, “Well, the fundamentals of the economy are strong.” And, we had recovered without much consequence from the myriad shocks since the 1950s. The big problem is that the inherent volatility in the economy is unknown. If investors deem volatility to be low, they take on more risk. When volatility is low, the value of the flexibility option is low. Individuals buy bigger homes, they don’t save, they believe that they will make money on their house as it appreciates in value and need little income to support it. We think our human capital is secure, so we borrow using credit cards, we borrow against our cars, and save little. The fundamental question is whether there are warning systems that will be built to provide a better picture of the true state of the risks in the economy.

Ed Baker: Is that any different, though, than simply misassessing risk?

Myron Scholes: Well, yes, we’re always going to misassess risk. How do we know the true state? It’s a time series¹⁴ world. We only have one run of history. The problem is that the converse is also true. If the world were actually calmer because we had learned to manage and to understand risk, the actions we took would have been just fine. With less underlying risk, we take more risk on personal account. However, it turned out the world wasn’t as calm as rating agencies, bankers, and others came to believe. There are some who argue that as the economy strengthens we should save for a rainy day by adding to capital requirements. However, we don’t know if the economy will continue to get stronger. Therefore, we saved for a rainy day, and it turned out to be costly to do so because no rain came. What we need to learn is not to “data mine” and weight recent experiences too heavily.

Geoff Gerber: From mid-September 2008 through March 2009, the New York Stock Exchange experienced twenty-seven (thirteen best and fourteen worst) of the forty (twenty best and twenty worst) most extreme daily returns since January 1966. The shocks seemed even more extreme than the 1987 one-day shock. Do you think that this is because people keep taking more and more risk, so that when volatility hits, it just hits wider and wider?

Myron Scholes: I think that there was a lot of information to adjust over a short period of time. What was the government going to do? What were international governments going to do? How much support was the Federal Reserve going to provide to the financial markets? What was the value of assets in financial entities, automobile companies, etc.? How were financial institutions going to save themselves from collapse? Obviously, with this shock in a complex global environment there was so much information to digest and

“ Generally, I would like to see more volatility in the markets. Small shocks remind us that a bigger shock might occur. And, we protect ourselves to some extent. ”

the adjustment costs were large. Generally, I would like to see more volatility in the markets. Small shocks remind us that a bigger shock might occur. And, we protect ourselves to some extent. Governments try to protect us against volatility. For example, every time there’s been a flood on the Mississippi River, we build a levee or a dam and then we tell people that it’s all right now, you can go back to your homes. But the levees fail from time to time and homes along the Mississippi continue to flood, and occasionally we get a gigantic hurricane or rain storm that destroys vast areas such as the effects of Hurricane Katrina. We have built homes in Los Angeles in areas where they theoretically should not have been built. As we put out fires, the underbrush grows, and each subsequent fire is larger and harder to put out. Will we be able to allow small fires to burn in the financial sector to burn out the underbrush? I don’t think so. And, it takes a long time to return to where we are cautious about risks and cognizant that we are subject to shocks. Now we have a new generation that has been burned so badly by this recent economic crisis that they will take too little risk. Or are we going to tell people not to take any risk, or will rules and regulations be put into place such that we take too little risk, and, as a result, it’s going to take a long time for the economy to recover? There is a need to gain more understanding about the effects of people’s beliefs about volatility on their behavior.

Meir Statman: There appear to be two kinds of errors: One is taking too little risk, and the second is taking too much.

Myron Scholes: Yes that is true. It’s an ex-post error, but not necessarily a before-the-fact error. But, as you say, it could be a before-the-fact error as well.

Meir Statman: The question is really whether it is an ex-ante kind of error. The bias of investment companies is to go toward too much leverage, rather than too little. Should there be an entity that pushes in the other direction?

Myron Scholes: If your assumptions are correct, then it’s worth study. I’m not saying that I know for sure, but, for example, let’s look at a hedge fund. If the fund takes on too much leverage or too much risk and it loses a lot of money, then it doesn’t have its business any more. There’s a tradeoff between staying in business over the long haul by taking less leverage and making a little money each period versus taking a lot of risk for an opportunity to make a lot of money over a few periods but with a high probability of being out of business. Both strategies are possible. The government and the

press are discussing compensation policies at banks, arguing that employees should be compensated in stock to dampen risk-taking. However, it did not help Lehman Brothers that Mr. [Robert] Fuld¹⁵ had a billion dollars in Lehman stock and lost it all. So perhaps rules that were put into place in 2001 about taxing executive compensation very heavily—above a million dollars in cash compensation—induced so many firms to give their executives stock that the executives started to take more risk because they figured out that if the company makes money, they can make a billion dollars for themselves. What behavioral implications or incentive implications do we create by the policies we put into place? A shock like we've had opens people's eyes and minds and encourages them to discuss and think about alternatives in light of what could happen. Hopefully we'll see evolution that is beneficial going forward. I hope that we don't shut off discussion too early for the sake of populist solutions to our problems.

Ed Baker: Listening to you, it sounds like these crises are just a natural part of market evolution, and perhaps we just have to know that they're going to happen periodically, and there is no way to avoid them.

Myron Scholes: I agree. The world is complicated; it's very, very complicated. Figuring ways to digest all of the information around us and come to the correct conclusion is very difficult. We can, however, use finance theory to help. Requiring greater capital, putting risk management on the same footing as producers within firms, encouraging better-trained risk managers, realizing the limits of our models and the inputs to models, providing for more control and measurement at the level of the board of directors, and warning of risks and measuring the effects of optionality are all steps that might dampen the consequences of these inevitable shocks. We shouldn't, however, attempt to build a moat around our city and pretend that that solves the problem. As we know, occasionally foreign invaders breach the moat and the city collapses.

Margaret Towle: Dr. Scholes, this has certainly been a very enlightening discussion, and we appreciate your willingness to share your insights with us.

Myron Scholes: My pleasure. One point that I would like to make in closing is new misunderstandings of the meaning of efficient markets. I think many people have come to the conclusion that if prices change by a lot that means that markets were inefficient. Efficient market theory does not claim that the price is 100-percent correct. I've always believed that if a stock is selling for \$100 today, it might be worth \$140 or \$80. What efficient markets theory tells me is that unless someone has information about the error or has a better model for understanding value, her best guess as to value would be the \$100 price (even though it is inaccurate). Other people have interpreted it in different ways—that efficient markets have failed, or that our belief in efficient markets has led to the wrong decisions. I don't think that link is correct.

Margaret Towle: Thank you again, and thank you to all of the advisory board members for your wonderful insights and

questions as well. We look forward to hearing more from you, Dr. Scholes.

Myron Scholes: I appreciate that. Thank you, all. 

Endnotes

- ¹ Milton Friedman (1912–2006) was a U.S. economist and statistician who was awarded the Nobel Memorial Prize in Economic Sciences in 1976. He served on The University of Chicago faculty from 1946 to 1977, helping to build an academic community of economists known as the Chicago School of Economics.
- ² Merton Miller (1923–2000) was a U.S. economist who shared the 1990 Nobel Memorial Prize in Economic Sciences with Harry Markowitz and William Sharpe for pioneering work in the theory of financial economics. He was a faculty member at The University of Chicago from 1961 until his retirement in 1993, and he served as doctoral thesis advisor for Dr. Scholes in the late 1960s.
- ³ In 1973, Fischer Black and Myron Scholes 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 standard deviation of the stock's return. Later that year, Robert Merton expanded the theory and coined the term "Black-Scholes model." As described by Dr. Scholes, the model is "an equation that prices options on common stock and provides a methodology to value options on securities generally. It can be used to measure risk and transfer risk." 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 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.
- ⁴ Dr. Scholes served on the board of directors of Long-Term Capital Management, 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 U.S. Federal Reserve to orchestrate a \$3.5-billion bailout by major U.S. banks and investment houses in September 1998. The fund closed in 2000.
- ⁵ Lehman Brothers declared bankruptcy on September 15, 2008. With more than \$600 billion in debt, it was the largest bankruptcy filing in U.S. history.
- ⁶ As outlined by the U.S. Department of the Treasury, a systemic risk regulator would be "a single entity [with] the ability to supervise, examine, and set prudential requirements for critical parts of our financial system." These "would not be limited to banks or bank holding companies, but could include any financial institution that was deemed to be systemically important in accordance with legislative requirements" as well as critical payment and settlement systems.

- ⁷ The Heisenberg uncertainty principle states that certain pairs of physical properties cannot both be known to arbitrary precision. That is, the more precisely one property is known, the less precisely the other can be known. This principle, which helped to form the cornerstone of quantum mechanics, was discovered in 1927 by Werner Heisenberg (1901–1976), a German theoretical physicist who also made major contributions to the fields of nuclear physics, quantum field theory, and particle physics.
- ⁸ 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 and others, building on earlier work by Harry Markowitz on diversification and modern portfolio theory.
- ⁹ In a normal bell-shaped distribution of portfolio returns, the majority of returns can be found in the “bell,” which centers around the weighted average return for the entire market. The ends, or tails, of the curve represent returns that are either extremely bad (left) or extremely good (right). Larger-than-normal tails are called “fat tails,” indicating more data on the extremes than expected. Fat tails indicate that extreme market moves were more likely than would be predicted by normal distributions.
- ¹⁰ The basic idea of putty-clay is that, before a choice is made, a wide range of options is available (i.e., the putty can be molded any way one chooses). Once that choice is made (i.e., the putty is baked into clay), the options become fewer. In economics, putty-clay describes an attribute of capital in financial models. Putty-clay capital can be converted from capital into durable goods, but cannot be converted back into reinvestable capital. This contrasts with putty-putty capital, which can be transformed from capital into durable goods and then back again.
- ¹¹ On October 16, 2009, Dr. Scholes participated in a discussion on the pros and cons of restricting the ability of financial institutions to create innovative products and the impact on the opportunity for world growth, held as part of the first annual Buttonwood Gathering at Pace University in New York, NY.
- ¹² The “theory of the second best” is a term used to describe a situation where one or more optimality conditions in an economic

model cannot be achieved. Lipsey-Lancaster (1956) proposed that if one optimality condition cannot be satisfied, reaching the second-best solution involves changing all of the other variables from those assumed to be optimal. According to this theory, if two or more markets are not perfectly competitive, efforts to correct only one of the optimality conditions may drive the economy further from efficiency.

- ¹³ From 1987 until 2006, Alan Greenspan (1926–) was the chairman of the U.S. Federal Reserve Board, which oversees the Federal Reserve Bank.
- ¹⁴ A time series is a sequence of data points, typically measured at uniform time intervals, such as the daily closing value of the Dow Jones Industrial Average. Time series forecasting predicts future data points based on known points in the past, for example, predicting the opening price of a stock based on historical daily values.
- ¹⁵ Richard S. Fuld, Jr. (1946–) was the chairman and chief executive officer of Lehman Brothers Holdings Inc. from 1994 until 2008, when the firm declared bankruptcy.

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