Chapter One

Introduction

Abstract: The theme of this book is that the application of Stochastic Optimal Control (SOC) is very helpful in understanding and predicting debt crises. The mathematical analysis is applied empirically to the financial debt crisis of 2008, the crises of the 1980s and concludes with an analysis of the European debt crisis. I use SOC to derive a theoretically founded quantitative measure of an optimal, and an excessive leverage/ debt/ risk that increases the probability of a crisis. The optimal leverage balances risk against expected growth. The environment is stochastic: the capital gain, productivity of capital and interest rate are stochastic variables, and for an insurance company, such as AIG, the claims are also stochastic. I associate the housing price bubble with the growth of household debt. A bubble is dangerous insofar as it induces a non-sustainable debt. This danger is exacerbated insofar as a complex financial system is based upon it.

The Financial Crisis Inquiry Commission (FCIC) was created to examine the causes of the financial and economic crisis in the US. It asked: How did it come to pass that in 2008 our nation was forced to choose between two stark and painful alternatives – either risk the total collapse of our financial system and economy or inject trillions of taxpayer dollars into the financial system?

While the vulnerabilities that created the potential for crisis were years in the making, the collapse of the housing bubble – fueled by low interest rates and available credit, scant regulation and toxic mortgages –was the spark that ignited a string of events, that led to a full-blown crisis in the fall of 2008. Trillions of dollars of risky mortgages had become embedded throughout the financial system, as mortgage related securities were packaged, repackaged, and sold to investors around the world. When the bubble burst, hundreds of billions of dollars in losses in mortgages and mortgage related securities shook markets and financial institutions that had significant exposures to those mortgages and had borrowed heavily against them. This happened, not just in the US but around the world.

Mortgage originators such as Countrywide sell packages of mortgages, household debt to the major banks. The latter in turn structure the packages and tranche them into senior, mezzanine and equity tranches. The income from the mortgages then flows like a waterfall. The senior tranche has the first claim, the mezzanine has the next and the

equity tranche gets what, if anything is left. The illusion was that this procedure diversified risk and that relatively riskless tranches could be constructed from a mélange of mortgages of dubious quality.

The securities firms finance the purchases from short term loans from banks and money market funds, either repos secured by mortgages or commercial paper. The securities firms then sell the collateralized debt obligations CDOs, the mezzanine and equity tranches as packages to international investors, investment banks such as Merrill Lynch, Citi-group, Goldman-Sachs and hedge funds. These purchasers finance the purchases by short term bank borrowing. Securities firms and hedge funds may buy Credit Default Swaps (CDS) from companies such as AIG as insurance against declines in the values of the CDOs. If the mortgagors are unable to service their debts – the income from the mortgages declines - the repercussions are felt all along the line. This is a systemic risk that was ignored.

Despite the post crisis expressed view of many on Wall St. and in Washington that the crisis could not have been foreseen or avoided, the FCIC argued there were warning signs. The tragedy was that Washington and Wall St. ignored the flow of toxic mortgages and could have set prudent mortgage-lending standards. The Federal Reserve was the one entity empowered to do so and did not.

Regulators had ample power to protect the financial system and they chose not to use it. SEC could have required more capital and halted risky practices at the big investment banks. It did not. The Federal Reserve bank of N.Y. (FRNY) and other regulators could have clamped down on Citigroup's excesses in the run up to the crisis. They did not. The dramatic failures of corporate governance and risk management at many systemically important financial institutions were a key cause of this crisis.

Many financial institutions as well as too many households borrowed to the hilt, leaving them vulnerable to financial distress or ruin if the value of their investments declined even moderately. As of 2007 the five major investment banks – Bear Stearns, Goldman Sachs, Lehman Brothers, Merrill Lynch and Morgan Stanley were operating with thin layers of capital - leverage ratios as high as 40:1. Less than a 3% drop in asset values would wipe out the firm.

A key institution in the financial crisis was AIG. At its peak it was one of the largest and most successful companies in the world. AIG's senior management ignored the terms and risks of the company's $79 billion derivatives exposure to mortgage related securities. The financial crisis put its credit rating under pressure, because AIG lacked the liquidity to meet collateral demands. In a matter of months AIG's worldwide empire collapsed.

The government was ill prepared for the crisis and its inconsistent response added to the uncertainty and panic in financial markets. It had no comprehensive and strategic plan for containment, because it lacked a full understanding of the risks and interconnection in the financial markets.

Prior to the crisis, it appeared to the academic world, financial institutions, investors, and regulators alike that risk had been conquered. The capital asset pricing model (CAPM) developed by Markowitz, Sharpe and Lintner explained the pricing of securities and how to manage risk. The options pricing model of Black, Scholes and Merton was used to construct financial derivatives with desired risk-expected returns combinations. Using these techniques, physicists, mathematicians and computer scientists – *the Quants* – were attracted to Wall St. to use good mathematics to manufacture financial derivatives.

Investors held highly rated securities they thought were sure to perform; the banks thought that they had taken the riskiest loans off their books; and regulators saw firms making profits and borrowing costs reduced. But each step in the mortgage securitization pipeline depended upon the next step to keep demand going.

The Fed and the IMF, who employed large numbers of PhD's in economics, were charged with surveillance of financial markets. The Fund surveillance reports reflect the state of the art – the quality of the models - in the economics profession. There was no fear of a financial crisis because the prevailing view was that they were the consequences of monetary excesses. The pre crisis period was the Great Moderation: moderate money growth and inflation and satisfactory real growth. Hence no cause to worry.

The Independent Evaluation Office (IEO) of the IMF assessed the performance of the IMF surveillance in the run up to the global financial crisis. It found that the IMF provided few clear warnings about the risks and vulnerabilities associated with the

impending crisis before its outbreak in the US and elsewhere. For example, in spite of the fact that Iceland's banking sector had grown from about 100% of GDP in 2003 to almost 1000% in 2007, the Fund did not recognize that this was a vulnerability that needed to be addressed urgently. Just before the crisis the IMF wrote that Iceland's medium term prospects remained enviable. They did not consider that Iceland's high leverage posed a risk to the financial system. The banner message was one of continued optimism after more than a decade of benign economic conditions and low macroeconomic volatility.

The IMF and the economics profession missed key elements that underlay the developing crisis. There was a "group think" mentality: this homogeneous group of economists in the Fund only considered issues within the prevailing paradigm in economics and there were no significant challenges to this point of view. The key assumption was that market discipline and self-regulation would be sufficient to stave off serious problems in financial institutions.

Neither the Fed nor the IMF discussed, until the crisis had already erupted, the deteriorating lending standards for mortgage financing, or adequately assessed the risks and impact of a major housing price correction on financial institutions. In fact the IMF praised the US for its light touch regulation and supervision that ultimately contributed to the problems of the financial system. Moreover, the IMF recommended that other advanced countries follow the US/UK approach. The Fund did not see the similarities between developments in the US and UK and the experience of other advanced economies and emerging markets that had previously faced financial crises.

The subject and contributions of this book

The Dodd-Frank bill (D-F) establishes the Financial Services Oversight Council. The bill authorizes the Federal Reserve Board to act as agent for the Council to monitor the financial services marketplace to identify potential threats to the stability of the U.S. financial system and to identify global trends and developments that could pose systemic risks to the stability of the US economy and to other economies. Neither the Fed nor the IMF, who based their analysis upon the dominant economic paradigm, has demonstrated its ability to fulfill these requirements. The techniques used by the Quants and rating

agencies, based upon the dominant stochastic models, proved inadequate.

The four major studies of the US financial crisis are: Greenspan's *Retrospective* (2010); the Financial Crisis Inquiry Commission *Report* (FCIC, 2011); Congressional Oversight Panel (COP, 2010) *The AIG Rescue*, Its Impact on Markets and the Government's Exit Strategy; Congressional Oversight Panel, (COP, 2009), *Special Report on Regulatory Reform*. There is a large economics literature on the crisis in conference volumes and journals. They cover the same ground as the four major studies above and are primarily descriptive. Several discuss regulation and capital requirements but their recommendations are not based upon an optimizing framework. They do not provide analytical tools to answer the questions: (Q1) What is a theoretically founded quantitative measure of an optimal leverage? (Q2) What is an excessive risk that increases the probability of a crisis? (Q3) What is the explanatory power of the analysis?

The *theme of this book* is that the application of Stochastic Optimal Control is very helpful in understanding and predicting debt crises and in evaluating risk management. I associate the housing price bubble with the growth of household debt. *A bubble is dangerous insofar as it induces a non-sustainable debt.* This danger is exacerbated insofar as a complex financial system is based upon it. My analysis uses Stochastic Optimal Control (SOC) to derive to answer questions (Q1) – (Q3) above. The optimal capital requirement/leverage balances risk against expected growth. The environment is stochastic: the capital gain, productivity of capital and interest rate are stochastic variables, and for an insurance company, such as AIG, the claims are also stochastic. In this manner the SOC approach developed in this book satisfies the requirements of the D-F bill described above.

There is a large economics literature that describes the crisis. There is a large mathematics literature on stochastic optimal control. My book synthesizes the two approaches. It is aimed at economists and mathematicians who are interested in understanding how SOC based techniques could have been useful in providing early warning signals of the recent crises, and at those interested in risk management. Key issues below are the subjects of the subsequent chapters and constitute the theme and contribution of this book.

Chapter 2 explains why the financial markets, and the Fed/IMF/economics profession, failed to anticipate the mortgage/ housing and financial crisis and the vulnerability of AIG. They used inappropriate models and hence incorrectly evaluated risk and the probability of bankruptcy/ruin. The crucial ultimate variable is the household debt, the mortgage debt. The rest of the financial system rested upon the ability of the mortgagors to service their debts. *Systemic risk* describes the effects of the failure of the mortgagors to service their debts upon the financial structure. The leverage of the financial system transmitted the housing market shock into a collapse of the financial system.

A bubble is in effect a large positive"excess, unsustainable debt". Detection of a bubble corresponds to the detection of an "excess debt". The aim of this book is to derive an optimal debt/net worth ratio and excess debt ratio. The latter is equal to the difference between the actual and the optimal debt. The fundamentals are reflected in the optimal debt. The housing price bubble, its subsequent collapse, and the financial crisis were not predicted by either the market, the Fed, the IMF or regulators in the years leading to the crisis. Moreover, the Fed and Treasury rejected the warnings based upon publicly available information, and successfully advocated deregulation of Over The Counter (OTC) markets. As a result, transparency of prices was reduced, risk was concentrated in a few major financial institutions, and high leverage was induced. These were basic ingredients for the subsequent crisis.

The Fed, the IMF and Treasury lacked adequate tools, which might have indicated that asset values were vastly out of line with fundamentals. The Fed and the Fund were not searching for such tools because they did not believe that they could or should look for misaligned asset values or excess debt, despite warnings from Shiller, some people in the financial industry, the GAO, state bank regulators and FDIC. The Fed was blind-sided by the Efficient Market Hypothesis (EMH), that current prices reveal all publicly available information. One cannot second- guess the market. There cannot be an ex-ante misalignment. Bubbles exist only in retrospect. The Jackson Hole Consensus gave them great comfort in adopting a hands off position by claiming that "As long as money and credit remain broadly controlled, the scope for financing unsustainable runs in asset prices should also remain limited….numerous empirical studies have shown that almost all asset

price bubbles have been accompanied, if not preceded by strong growth of credit and or money". Since the period preceding the crisis was the Great Moderation, there was no need to worry.

So it was not just a lack of appropriate tools that undid the Fed; it was a complete lack of appreciation of what its role should be in heading off an economic catastrophe. There are two separate but related questions: Are identification and containment of a financial bubble legitimate activities of the Fed, and if they are, what are the best tools to carry out this analysis.

Former chairman of the Federal Reserve Board Alan Greenspan has great knowledge of financial markets. I think that his behavior may be explained rationally. First he understands that the function of financial markets is to channel saving into investment in the optimal way to promote growth. Second, like most of the economics profession, he or his staff accepted the generality of the *First Theorem of Welfare Economics*. This theorem states that a Competitive Equilibrium is a Pareto Optimum. The implication is that "market regulation" is superior to regulation by bureaucrats, politicians. Do not try to second guess the markets.

The belief in the generality of the *First Theorem of Welfare Economics* may have provided a basis for Greenspan's position. The Theorem does not hold in financial marketsfor several reasons. First, financial assets are not arguments in the utility function of households so that it makes little sense to say that the relative asset prices equal marginal rates of substitution. There is no tangency of indifference curves with the price line. Second, the assumption of atomistic agents operating in perfectly competitive markets with full information and stable preferences is wildly unrealistic. The Efficient Market Hypothesis EMH was a major foundation of Greenspan's view and that of the finance profession.

Chapter 3 considers the role of the "Quants"/mathematical finance. They are the physicists, mathematicians and computer scientists who were attracted to Wall St. The mathematics per se was not at fault in the crisis, but the finance models used were inadequate and grossly underestimated risk.

The finance literature was based upon the Efficient Market Hypothesis (EMH), the Black-Scholes-Merton (BSM) options price model and the CAPM. The EMH claims

that asset markets are, to a good approximation, informationally efficient. Market prices contain most information about fundamental value. Prices of traded assets already reflect all publicly available information. The CAPM provides a good measure of risk. Assets can only earn high average returns if they have high betas. Average returns are driven by beta because beta reflects the extent that the addition of a small quantity of the asset to a diversified portfolio adds to the volatility of the portfolio. On the basis of the EMH and CAPM, Greenspan, the Fed and the finance profession believed that markets would be self-regulating through the activities of analysts and investors. Government intervention weakens the more effective private regulation.

Securitization/tranching, the CDOs and derivatives of derivatives produced an environment where the EMH/CAPM lost relevance. These bundles of many mortgage based securities seemed to tailor risk for different investors. Securitization/tranching gave the illusion that one could practically eliminate risk from risky assets and led to very high leverage. Ratings of the tranches were not based upon the quality of the underlying mortgages. They were all in the same bundle. The rating depended upon who got paid first in the stack of loans. The key question was how to rate and price the tranches. The issue concerned the correlation of the tranches. If a pool of loans started experiencing difficulties, and a certain percent of them defaulted, what would be the impact upon each tranche? The "apples in the basket model" assumed that they were like apples in a basket with a certain fraction of them being rotten. If one apple is rotten, it says nothing about whether the next apple chosen is rotten. Another very different one is "the slice of bread in the loaf" model. In that model if a slice (tranche) of bread is moldy, what is the probability that the next slice – or the rest of the loaf – is moldy? The Quants falsely assumed independence of tranches and assumed that they could tranche packages of "toxic assets" to produce a riskless tranche.

The Quants ignored how the interactions of the firms affected the return on the CDOs. The collapse of one group led to severe losses in groups before and after it in the chain. For example, the collapse of AIG affected the prices of "safe" as well as of risky assets. They based their estimates of risk upon the recent non-sustainable distribution of housing prices. They ignored the "no free lunch" constraint that capital gains cannot consistently exceed the mean interest rate. Most important, they ignored publicly

available information concerning systemic risk. Their models ignored the systemic risk that the mortgagors would be unable to repay debt. The prices of many of the securities traded were opaque and estimated using arbitrary computer models. Hence the values of assets and liabilities on balance were not reflective of what they could fetch if sold.

Chapter 4 discusses the philosophy of the stochastic optimal control (SOC) techniques used in later chapters 5 – 7. Modeling is crucial in economics and finance. Fisher Black, who developed the equation for options modeling, argued that given the models' limitations, "the right way to engage with a model is, like a fiction reader or a really great pretender, is to suspend disbelief and push it as far as possible... But then, when you've done modeling, you must remind yourself that ... although God's world can be divined by principles, humanity prefers to remain mysterious. Catastrophes strike when people allow theories to take on a life of their own and hubris evolves into idolatry."(quoted in Derman).

The net worth of the real estate sector in chapter five, and of AIG on chapter six, evolve dynamically. In the first case, debt is incurred in period t to purchase assets whose return is uncertain, and must be repaid in period t+1 at an uncertain interest rate. In the second case, insurance is sold in period t and the claims in period t+1 are uncertain. What is the optimal debt in the first case and what are the optimal insurance liabilities in the second case?

I discuss the strengths and limitations of alternative criterion functions, what should the firm or industry maximize? How should risk aversion be taken into account? Then I discuss the modeling of reasonable stochastic processes of the uncertain variables. Given the criterion function, each stochastic process implies a different quantitative, but similar qualitative, optimum debt/net worth or insurance liabilities/net worth. Using SOC I derive quantitative measures of an optimal and an excessive leverage, an excessive risk that increases the probability of a crisis. The optimal capital requirement or leverage balances risk against expected growth and return. The implications of the analysis are described graphically in the text and proved mathematically in an appendix. As the actual debt ratio exceeds the optimal ratio the expected growth declines and the risk rises. Thereby the probability of a debt crisis is directly related to the excess debt, the actual less optimal. A bubble is an unsustainable excess debt. The second part of the chapter

discusses the models used in the insurance, or actuarial literature, concerning the probability of ruin. They are then compared with the SOC approach.

Chapter 5 applies this SOC analysis to the US financial crisis. I discuss the importance of the housing/real estate sector to the financial sector, and the characteristics of the mortgage market. Then two models of the stochastic process on the capital gain and interest rate are presented. Each implies a different value of the optimal debt/net worth. In order to do an empirical analysis, I derive an upper bound of the optimal debt ratio, based upon the alternative models, to derive a measure the excess debt: actual less the upper bound of the optimal ratio. The derived excess debt is shown to be an early warning signal (EWS) of the debt crisis as early as 2004.

Finally, the shadow banking system is discussed. The financial crisis was precipitated by the mortgage crisis for several reasons. First, a whole structure of financial derivatives was based upon the ultimate debtors – the mortgagors. Insofar as the mortgagors were unable to service their debts, the values of the derivatives fell. Second, the financial intermediaries whose assets and liabilities were based upon the value of derivatives were very highly leveraged. Changes in the values of their net worth were large multiples of changes in asset values. Third, the financial intermediaries were closely linked – the assets of one group were liabilities of another. A cascade was precipitated by the mortgage defaults. Since the "Quants" were following the same rules, the markets could not be liquid. In this manner, the mortgage debt crisis turned into a financial crisis.

Chapter 6 concerns insurance, the AIG case. First, I describe what happened to AIG in the 2007-08 crisis. Then I evaluate the actuarial literature on optimal risk and capital requirements for insurers – Cramér-Lundeberg, ruin problems. I explain how SOC is a much more powerful tool of analysis . The stochastic optimal (SOC) approach's components are: the criterion function, the stochastic differential equations, and the stochastic processes. The solution for the optimal insurance liability/claims requirement on the basis of SOC follows. The chapter concludes with an evaluation of the government bailout.

AIG seriously underestimated risk because it ignored the negative correlation between the capital gain on insured assets and the liabilities/claims on AIG. The CDS claims grew when the value of the insured obligations CDO declined. This set off

collateral requirements, and the stability of AIG was undermined. The chapter concludes with an evaluation of the government bailout.

Chapter seven concerns the agricultural crisis of the 1980s and the S&L crisis in the 1980s. I explain that these crises had many features in common, but were localized. The crisis of 2007-08 shared the common elements of the earlier two but was more pervasive and severe due to the financial structure that was based upon the housing/mortgage sector. This focus is upon the crisis of the 1980s, in particular the agriculture crisis. The policy issues are: How should creditors, banks and bank regulators evaluate and monitor risk of an excessive debt that significantly increases the probability of default? I show how the same techniques of stochastic optimal control used in chapters five and six are useful in providing early warning signals for the agricultural crisis. In the concluding part I compare the S&L crisis to the agricultural crisis.

Chapter eight goes beyond the US financial crisis of 2008 and explains the inter country differences in the debt crisis in Europe. This subject is timely and I cannot ignore it. The external debts of the European countries are at the core of the current European crises. Generally, the crises are attributed to government budget deficits in excess of the values stated in the Stability and Growth Pact (SGP)/Maastricht treaty. Proposals for reform generally involve increasing the powers of the European Union to monitor fiscal policies of the national governments and increasing bank regulation.

I explain: (a) to what extent the crises in the different countries were due to government budget deficits/government dissaving or to the private investment less private saving, (b) what is the mechanism whereby the actions of the public and private sectors lead to an unsustainable debt burden, defined as the ratio of debt service/GDP. The Stability and Growth Pact/Maastricht Treaty and the European Union focused upon rules concerning government debt ratios and deficit ratios. They ignored the problem of "excessive" external debt ratios in the entire economy that led to a crisis in the financial markets.

The techniques of analysis in this chapter differ from those in the previous chapters. In the previous chapters the debt ratio was a control variable. Using stochastic optimal control, I derived optimal debt ratios. This is *normative* economics. Chapter eight is concerned with *positive* economics. The external debt ratio is not a control variable, but

is an endogenous variable that is determined by "fundamentals" in a dynamic manner. The "fundamentals" are determined by the actions of both the public and the private sectors. I explain this by drawing upon the Natural Real Exchange Rate NATREX model (Stein, 2006) of the equilibrium real exchange rate and external debt – the endogenous variables.

In this book, I do not discuss policy issues: regulation and reform. A Dissenting Statement by Wallison, in the Financial Crisis Inquiry Commission Report is: "The question that I have been most frequently asked about the Financial Crisis Inquiry Commission [FCIC] is why Congress bothered to authorize it all. Without waiting for the Commission's insights into the causes of the financial crisis, Congress passed and the President signed the Dodd-Frank Act (DFA), [with] far reaching and highly consequential regulatory legislation." The focus of my book is positive economics, and I avoid the political, normative, divisive and sociological aspects that regulation entails.

The history of this book reflects my debts to many people. When I retired from the economics department I was invited in 1997 by the Division of Applied Mathematics (DAM) to be a visiting professor/research. I had worked with Ettore Infante (DAM) for a decade in the 1960s - 1970s applying deterministic optimal control to economic problems in feedback form. I felt that I was returning home. Wendell Fleming and I started to discuss how and to what extent the techniques of stochastic optimal control can be useful in economics. Wendell is renowned for his contributions to pure and applied mathematics, and his book with Ray Rishel is essential reading. We decided that the debt crises would be an appropriate subject of interdisciplinary research. Thus I had to learn the mathematics literature using dynamic programming to determine what is an optimal trajectory of the debt. Our regular meetings resulted in our first article, Fleming and Stein (2004) in the Journal of Banking and Finance. I was invited to give a paper at the AMS-IMS-SIAM Research Conference in Mathematical Finance (2003), where I explained how one can successfully apply the techniques of the H-J-B equation to the crises of the 1980s. This was my first contact with the elite in the profession. They were masters of the techniques but were unaware of what one could do with them for real world problems in economics. I edited and contributed to a special issue of Australian Economic Papers "Stochastic Models in Economics and Finance" (2005). I was then invited to give a paper

at a mathematics conference at the University of Wisconsin/Milwaukee applying the mathematical techniques to the US balance of payments. There I got to know Ray Rishel, who has been most helpful to me. I then edited and contributed to a Special Issue of the Journal of Banking and Finance "Intertemporal Optimization in a Stochastic Environment" (2007).

EUROPT invited me twice, once to Prague and once to Lithuania, to give keynote addresses about different aspects of my work. I was the only economist on the programs, the rest were mathematicians and O/R experts.

The next phase consisted of writing a series of articles aimed at economists under the rubric " Greenspan, Dodd-Frank and Stochastic Optimal Control". My aim was to explain how the failures of the Fed could have been avoided had the Fed used my techniques.

I felt that I had done all that I could to bring my work to the attention of the various professions. However, the Springer-Science editor Brian Foster wrote that there are many books on stochastic control and many descriptive books on the crisis, but none applied the techniques of SOC to the crises. Would I consider doing a book on the subject? Springer published Fleming-Rishel, so my book would be a nice complement.

It was unclear to me who could be the readership? I consulted Seth Stein, the author of Disaster Deferred on earthquake prediction. His advice was to write the book that I want to write and not write it with any specific constituency in mind. He suggested how I should present the mathematics in a way that both mathematicians and economists would benefit. He has been a constant source of excellent advice.

I had the good fortune to receive the advice and criticism from several sources. Peter Clark, Serge Rey, Karlhans Sauernheimer, Christoph Fischer and Carl D'Adda have been my economics critics. They have suggested many changes in points of view. Wendell Fleming and Ray Rishel have been my mathematics critics. Ren Cheng (Fidelity Investments) and Robert Selvaggio (Rutter Associates) have my consultants on what has been going on in the finance industry.

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