Work In Progress
Measuring and Managing Risk in Innovative Financial Instruments

Stuart M. Turnbull*
Bauer College of Business, University of Houston

May 18, 2009

Abstract

This paper discusses the difficult challenges of measuring and managing risk of innovative financial products. To measure risk requires the ability to first identify the different dimensions of risk that an innovation introduces. The list of possible factors is long: model restrictions, illiquidity, limited ability to test models, product design, counterparty risk and managerial related issues. For measuring some of the different dimensions of risk the implications of limited available data must be addressed. Given the uncertainty about model valuation, how can risk managers respond? All parties within a company - senior management, traders and risk managers - have important roles to play in assessing, measuring and managing risk of new products.

1 Introduction

In the current credit crisis, the issues of improper valuation and inadequate risk management in the use of credit derivatives have been at the center of the credit market turmoil. There has been much discussion about the use of such instruments as mortgage backed securities, collateralized debt obligations and credit default swaps. The crisis raises the questions of

*I am grateful for comments and suggestions from M. Crouhy, R. Jarrow, C. Pirrong, D. Rowe, C. Smithson, L. Wakeman and seminar participants at the Bauer College and the Financial Innovation & Crisis Conference, organized by the Federal Reserve Bank of Atlanta.

how do we measure the risk of innovative financial products and how do we manage the risk? Innovative financial instruments are typically illiquid and pose several challenges for their valuation and the measurement and management of the risk. To measure risk at some specified time horizon requires the ability to price different assets in future states and to compute different risk measures. To manage risk requires ways to alter a risk profile, either through contractual mechanisms, such as master agreements, or institutional such as clearing house, or via the use of hedging instruments. This paper addresses some of the many issues that arise when a new form of financial instrument is introduced.

Innovation in financial instruments has taken two forms: variations on existing types of instruments and instruments introduced on new classes of risk. Examples of the first type of innovation would be swaptions, lookback options and exchange options and for the second type credit derivatives, catastrophe bonds and derivatives on volatility. In the first case, there are developed markets for the underlying assets, while in the second case the markets are new. The different forms of innovation introduce their own set of issues. Here we will focus mainly on the second form of innovations and address the questions of how do we price such instruments and perform risk management.

To illustrate many of the different issues that arise when considering a new form of financial innovation, we consider a particular example of an innovation. However, we stress that the focus is on general issues that arise and the analysis is applicable for any form of instrument. Given that credit derivatives have been the catalysis for the credit crisis, we consider the issues that arise in the pricing of credit derivatives written on a portfolio of obligor related assets. For example, the portfolio could be residential mortgages, credit cards, bonds, or derivatives. Each asset will generate a cash flow provided that default does not occur. The event of default will generate a terminal payment. The focus will be on the general issues that arise and not on minute contract details.

We first start in section two with issues relating to pricing, similar issues being relevant for risk management. For a collateralized debt obligation (CDO), there are two different approaches: a bottom-up approach and a top-down approach. The bottom-up approach models the individual assets in the collateral pool of the CDO. To model the cash flows generated by the collateral pool it is necessary to model the default dependence amount the assets. This has been the Achilles' heel for valuation and risk management in the current crisis. The top-down approach directly models the cash flows from the collateral pool, ignoring the explicit constituents of the collateral pool. For innovations, there is often limited data available, which implies that for models used either for pricing or risk management can not be too complicated. There is a real trade-off between the need to estimate parameters and the availability of data.

The design characteristics of an instrument affect both the demand side and the supply side. End users will use an instrument if it provides some service at a lower cost than what is currently possible. To stimulate the supply side, there should be ready mechanisms to offset set the risk. The design affects the cost of hedging. In turbulent conditions, certain features in the design may make an instrument usually sensitive to shocks in the economy or market disruptions. Design characteristics are discussed in section three.

With any new innovation there will initially be limited liquidity. In section four we discuss the factors that influence the level of liquidity. There are many factors, such as the ability to grow both the supply and demand, the ease of pricing, the transparency of the pricing process, the existence of hedging tools, the costs associated with hedging and the ability to observe posted prices on a regular basis that provide investors with information about liquidity and market depth. The ability to hedge and speculate makes an instrument attractive to a wide range of investors. However, the participation in the market by some investors will be sensitive to macro-shocks. If the investors are forced to leave a market, unwinding positions will increase price volatility and affect liquidity.

Counterparty risk affects all contracts. With an innovation, the difficulties in estimating the effects of this form of risk are increased. First, there is little information available to help in specifying the joint distribution modeling default between the innovation and the counterparty. Second, for an innovation, there is the need to develop the back office facilities to handle trades and to keep track of the different counterparties. Third, if collateral has been posted, it is necessary to consider how the value of the collateral varies with the credit worthiness of the counterparty. In section five we discuss these issues, as well as the use of master agreements and clearing houses.

Risk management requires the ability to generate the probability distribution describing the value of a portfolio of assets at some future specified horizon. For an innovation there is usually limited data, which restricts the complexity of models. If the parameter values are set so that model prices match a subset of extant prices (that is, they are calibrated) then the effects of model misspecification and limited liquidity are compounded into the parameter values, increasing the variability of these parameters. Limited data also implies that model testing will be difficult. While a model may be calibrated to match a subset of prices, there is no guarantee that the model will be useful for hedging. If a model is deficient, stress testing may give the risk manager a false sense of security. Scenario analysis is one way to address the uncertainty surrounding model valuation. However, this requires managers to think outside the confines of their modeling framework.

There are a number of managerial issues that can greatly impact the risk management function. When an innovation is introduced, often an existing accounting system is used without regard as to whether it will generate perverse incentives for traders. A trader might undertake a trade that enhances a bonus, though it may not be in the best long run interests of the firm. In an environment where there is a constant flux of innovations, senior management is often ignorant about the exact nature of the innovations and refuses to acknowledge their lack of knowledge, relying on their traders and quants for guidance. This affects their ability to exercise independent judgment about the risk characteristics of an innovation. There are many costs associated with an innovation arising from operational and legal risk that are neglected when it is marked-to-model, implying the innovation is over valued. Risk management issues are discussed in section six.

For certain types of instruments a credit rating is often a prerequisite in order to increase the marketability of the innovation. For a risk manager or investors not involved in any issuer/rater discussions, the methodology used to determine the ratings is not transparent. In the recent credit crisis, we have seen that rating agencies did a poor job in assessing the credit worthiness of recent innovations. This implies that if ratings are used, it is essential that risk managers understand what they mean, how they are derived and the accuracy of the methodology. For innovations there is no history, so the challenge is to interpret what information a rating actually conveys and how to use a rating. We address these issues in section seven.

The last section summarizes the conclusions.

2 Pricing

At the center of the credit crisis has been the issue of how to price different types of collateralized debt obligation (CDO). Here we consider some general form of CDO structure and identify some of the different issues that must be addressed both for pricing and hedging. For a CDO there are two ways to tackle the issue of pricing: a bottom-up approach and a top-down approach. A bottom-up approach starts by modeling the event of default and the loss given default for the individual assets in the collateral pool of the CDO.[1] The use of any form of realistic model requires the estimation of model parameters, implying that there is a trade-off between the complexity of the model and the availability of data. The ability to model the behavior of individual assets in the collateral pool depends on the na-

[1] The precise nature of the assets we leave unspecified. Examples of possible candidates would be mortgages, asset backed securities or credit default swaps on asset backed securities.

ture of the assets. In some cases the assets may be derivatives, which adds a new layer of complexity. A simple case would be a credit default swap written on a bond or a loan. A far more complicated case would be mortgage backed bonds issued by a mortgage trust. While the bottom-up approach is a logical starting point, for some types of assets the approach is infeasible, as either the data requirements become over whelming or the underlying assets too complex. This necessitates taking a top-down approach.

2.1 Basic Set-up

We start with the basic set up. Initially we work in continuous time framework, though a discrete time approach could also be employed. In simulations a discrete time framework is usually employed. We assume a probability space $(\Omega, \mathcal{F}, Q)$ and a filtration $(\mathcal{F}_t; t \geq 0)$ satisfying the usual conditions - see Protter 1993. A stopping time has an intensity process $\lambda(t)$ with $\int_0^t \lambda(s)ds < \infty$ for all t. Given no default up to time t, the probability of default over the next interval Δt is approximately $\lambda(t)\Delta t$. A default time for obligor k generates a default process $N_k(t)$ that is zero before default and one after default. The probability of obligor k surviving until time t is given by

$$P[\tau_k > t] = E^Q[\exp[-\int_0^t \lambda_k ds]|\mathcal{F}_0] \tag{1}$$

Default can arise from events that are unique to the obligor or sector or through dependence on common economic factors. For example, in the current credit crisis the fall in house prices has been one of the major drivers of default. The collapse of Enron was due to factors unique to the firm, in this case fraud. We assume that default for obligor k, $k = 1, ..., m$, depends on a set of measurable covariates denoted by the vector $X_k(t)$ - see Lando (1994, 1998). The probability of no default over the period $[0, t]$ is given by

$$P[\tau_k > t] = E[\exp[-\int_0^t \lambda_k(X_k(s))ds]|\mathcal{F}_0] \tag{2}$$

The value of a zero coupon bond that pays one dollar at time T if no default and zero otherwise is given by

$$\bar{B}_k[0, T] = E^Q[A(T)1_{(\tau_k > t)}|\mathcal{F}_0] \tag{3}$$

where $1_{(\tau_k > t)}$ is an indicator function that equals one if the $(\tau_k > t)$, zero otherwise and $A(T)$ is the numeraire appropriate for the pricing measure Q. If the numeraire is the money market account then we have[2]

$$\bar{B}_k[0,T] = E^Q[\exp(-\int_0^T r(u) + \lambda_k(u)du)\ |\mathcal{F}_0] \tag{4}$$

where $r(t)$ is the instantaneous spot interest rate. To evaluate the above expression we must make assumptions about the distributions that describe the evolution of the spot rate and intensity function.

2.2 Modeling Assumptions

For the instantaneous spot interest rate the standard assumptions are either Gaussian, Feller diffusion processes, possibly with jumps - see Dai, Le and Singleton (2006)- or Lévy processes, see Ederlin and Ozkan (2003). For the intensity process, Gaussian processes have been assumed, as they facilitate easy to compute closed form solutions. However, they do imply that the intensity function can be negative. Duffie and Singleton (1999) assume that both the spot interest rate and the intensity rate are described by Feller processes. These assumptions imply that given parameter restrictions, these processes are strictly positive. Ederlein, Kluge and Schönbucher (2006) describe the intensity function using Lévy processes. Lando (1994, 1998) models the intensity function as a Cox process, a typical example being

$$\lambda_k(t) = \sum_{j=1}^{m} b_{k,j} x_j(t) \tag{5}$$

where $\{b_{k,j}\}$ are coefficients and $\{x_j\}$ covariates. Restrictions must be placed on the processes for $\{x_j(t)\}$ to ensure that they are positive. If the coefficients $\{b_{k,j} > 0\}$ are positive, then the intensity is positive. These sign restrictions greatly complicates empirical estimation and consequently are often ignored. For references to extant literature see Schönbucher (2003). Instead of Feller processes, a quadratic formulation can be applied:

$$\lambda_k(t) = [\sum_{j=1}^{m} b_{k,j} x_j(t)]^2 \tag{6}$$

where $\{x_j\}$ are covariates described by Gaussian processes. For empirical estimation, no restrictions need be placed on the signs of the coefficients.

[2] This approach for pricing credit risky assets, called the reduced form approach, was first introduced by Jarrow and Turnbull (1995).

2.3 Bottom-up Approach

To price the tranches of a CDO requires modeling the cash flow generated by the assets in the collateral pool. In a bottom-up approach, for each asset in the collateral pool, the process describing the event of default and the loss given default must be estimated. To model the cash flow generated by the assets in the collateral pool necessitates considering how the event of default by one asset will affect the remaining assets. The state of the economy will in general affect the credit worthiness of obligors. Similarly, events in a particular sector will affect the obligors belonging to that sector. Default by one obligor may be beneficial to remaining obligors due to the reduced competition or it may signal the perilous state of a sector of the economy. The issue is how to model the default dependency among the assets.

The factor model described by expression (6) is one possible way to model default dependence, if some of the covariates $\{x_j\}$ are common to all assets, describing the either the macro state of the economy or a sector. A popular alternative is to use a copula function to model the joint distribution for defaults. The basic model used for pricing and risk management has been the normal copula. CreditMetrics generalized the Merton (1974) model to describe the probability of n obligors defaulting. Li (2000) showed the model could be formulated in terms of a normal copula. Copula function knit together the marginal distribution functions to give the joint distribution[3]. The normal copula is defined as

$$c(u_1, ..., u_n) = \Phi_{n,\Sigma}(\Phi^{-1}(u_1), ..., \Phi^{-1}(u_n))$$

where u_i, $i = 1, ...n$, are realizations of uniform random variables; $\Phi_{n,\Sigma}$ is the n dimensional multi-variate normal cumulative distribution function with zero mean and correlation matrix Σ. The critical issue for application is the specification of this correlation matrix. In the Merton (1974) model, it is the correlation of asset returns. The attraction of the normal copula is its simplicity.

Once the correlation matrix is specified then it is possible to generate the distribution of the default times for the n obligors. From the distribution multivariate normal distribution with zero mean and correlation matrix Σ, draw realizations $x_1, ...x_n$ and then map onto the unit interval $u_i = \Phi(x_i)$. For risk management, a credit rating transition matrix can used to infer the new credit class for each obligor. For pricing, the marginal distribution describing the event of default for each obligor is inferred from credit default swap prices. The default time can then be inferred - see Schönbucher (2003, p331). For pricing different

[3] For an introduction to the use of copula functions applied to finance, see Schönbucher (2003, ch. 10) and O'Kane (2008, ch. 14).

tranches on a credit index, the correlation[4] is usually taken as an input parameter and is calibrated to match the price of the equity tranche. Not surprisingly, the other tranches are misplaced, giving rising to a skew in what is called base correlation. To address the existence of this skew, a whole family of latent factor models have been introduced[5]. The marginal distributions are calibrated to match extant credit default prices. The default dependency among obligors is described by the common latent factors. This use of factor models reduces the number of parameters that must be estimated[6].

We know from the work of Acharya, Bharath and Svrivinisan (2003) and Altman, Resti and Sironi (2005) that recovery rates depend on more than one factor and vary with the state of the economy. This affects the loss distribution, as default probabilities and recovery rates are negatively correlated: if the state of the economy is declining and the frequency of defaults increasing, recovery rates decrease. This implies that it is necessary to jointly model the probability of default and the loss given default. This is a non-trivial undertaking. Dullmann and Trapp (2004) test a number of different latent factor models.

The event of an obligor defaulting will in general affect the credit worthiness of other obligors. The effects may be positive or negative depending on the nature of the default, the size of the obligor and the relationship of the obligor with other firms. If the default reduces competition, then it may be beneficial if remaining obligors are competitors. If the remaining obligors are suppliers to the defaulting obligor, then the effects of the default may be negative. This implies that to model the effects of default on other obligors requires a detailed analysis. There are many papers that have developed models describing the consequences of default on other obligors[7]. The challenge with these types of models is that they are difficult to calibrate, implying that their predictions are problematic. To-date, we have no extensive empirical results for these models.

The central issue, either for pricing or risk management, is whether the modeling at the level of the obligor is capable of generating a realistic loss distribution for the whole portfolio.

[4] It is usually assumed that are correlations are the same.

[5] See Andersen (2006) for a description of these models and references to extant literature.

[6] See Burtschell, Gregory and Laurent (2005) for an analysis of the performance of widely used copula for pricing.

[7] For a description of these types of models see Jarrow and Yu (2001), Gagliardini and Gourieroux (2003) and Yu (2007).

2.4 Top-down Approach

A top-down approach directly models the cash flows generated by the portfolio of assets in the collateral pool without explicit identification of individual assets, thus reducing the magnitude of the problems associated with parameter estimation identified in the last section. The typical formulation assumes that there are a number of different types of events that cause a loss to occur. Each time an event occurs, the portfolio suffers a loss, the size of the loss depending on the type of event. The arrival of each type of event is modeled by Poisson processes. The intensity of arrival is assumed to be stochastic. With this approach the number of parameters that must be estimated is greatly reduced. For example, in Longstaff and Rajan (2008) there are three types of events. The interpretation of these events being that one type of event models default by individual obligors, the second event sector or group defaults and the third event economy wide defaults. In the simplest form of the model there are of six parameters to estimate: three jump sizes and three volatilities. The benefit of this parsimony is that models can usually be calibrated, while the cost is that the model may do a poor job in describing the dynamics of the prices of different structures over time.

2.5 Implications for New Innovations

For new financial products there is a real trade-off between the complexity of models and the availability of data. A bottom-up approach is a logical starting point to model the loss distribution generated by a portfolio of obligors. The critical issue is that of modeling default dependence.

The copula approach is simple, though static. The use of the normal copula is perhaps the least demanding in terms of the number of parameters that must be estimated. For risk management, a credit rating transition matrix is used and a multi-factor equity return model to generate the correlation matrix. For pricing, credit default swap prices are used to infer the intensity for each obligor. It is usually assumed the recovery rate is some fixed known value. Often equity returns are used to generate the correlation matrix, though there is little theoretical justification. Alternatively, the correlation matrix is assumed to be described by one parameter that is calibrated so that the model price matches the price of one tranche, usually the equity tranche. In practice, for pricing both the bottom-up and top-down approaches rely on calibration. The limitation of this approachy is that model imperfections and the lack of liquidity of prices are impounded into the calibrated parameters.

The reduced form approach introduces default dependence via the specification of the intensity function. If a Cox process is assumed for the intensity function, then a time series of credit default swap prices is required to allow estimation. Consider a simple Cox process of the form

$$\lambda_k(t) = b_{k,0} + b_{k,1}x_1(t) + b_{k,2}x_2(t)$$

where $x_1(t)$ and $x_2(t)$ are covariates described by some type of stochastic process and $b_{k,0}$, $b_{k,1}$ and $b_{k,2}$ are coefficients. Simple types of processes usually require 3 parameters to be estimated for each covariate plus a correlation coefficient, implying 7 parameters. There are 3 coefficients, so a total of 10 parameters must be estimated. For a credit default index, the constituent members belonging to the index change every six months, implying that there is approximately 128 trading days. There is a real trade-off between the complexity of the model and hence the number of parameters versus the availability of data. This is especially the case when the collateral pool is composed of bonds written on either subprime mortgages or credit cards and issued by an asset backed trust. This introduces a lot of complications. The underlying assets in the pool are asset backed bonds. However the behavior of these bonds depends on the type of mortgages or credit cards in the trust and the waterfall that divides the cash flows generated by the trust to the different tranches. It becomes very difficult to model the behavior of the asset backed bonds, especially as these bonds are rarely traded. Data about the underlying assets for the bonds (for example, subprime mortgages or credit cards) is often not available.

In some cases a model is calibrated to match the prices of tranches on an index, where the asset pool is different from the assets in the pool of the CDO under consideration, making parameter calibration even more unreliable. This difficulty arises because of the lack of data for the new product.

2.6 Summary

In this section we have discussed some of the issues that arise when trying to price new financial products. A bottom-up approach is a logical starting point for modeling the event of default and the loss given default for individual obligors in the collateral pool. To model the cash flows generated by the collateral pool requires describing the nature of the default dependence among the assets. However the limited availability of data constrains the complexity of models. In an attempt to reduce the problems of limited data, a top-down approach directly models the cash flows generated by the collateral pool.

Often models are calibrated to a subset of extant prices. The limited liquidity of prices and the deficiencies of the model are impounded into model parameters. The limited data implies that there is little, if any, empirical evidence about the accuracy of a model and its ability to hedge. For new products, data limitations imply that if even if models are calibrated to match a subset of prices, there is uncertainty about posted model prices, especially for products that are highly illiquid. This affects not only trading but also risk management.

3 Design Characteristics

The design of an instrument defines its risk sharing characteristics and appeal to different clienteles of potential users.[8] To stimulate usage, the design should attempt to anticipate features that will appeal to end users. On the demand side it should help to reduce the costs of achieving some service, such as altering the risk profile facing an investor. On the supply side, it should be designed to reduce the costs associated with hedging, such as how its meshes with the features of extant instruments that can be used for hedging. For example, the roll over dates for credit default swap indices match the International Monetary Market dates. This matching of maturities helps if LIBOR futures are used as a hedging tool.

The design of the innovation directly affects its risk characteristics. To identify the risk characteristics of a new instrument, requires identifying the condition under which different features of an instrument affect its risk profile. Certain design features may make an instrument extremely sensitive to underlying factors and market disruptions. We demonstrate the first point via a simple example that produced a domino effect in mortgage collateralized debt obligations and the second point by examining asset backed commercial paper.

3.1 Factor Sensitivity

We consider how the design of subprime collateralized debt obligation (CDO) tranches made the tranches quite sensitive to the state of the housing market. The nature of the risks involved in holding a triple-A rated super-senior tranche of a subprime CDO was completely missed by all the players: rating agencies, regulators, financial institutions and investors.

The underlying assets in a subprime CDO were mortgaged backed bonds. These bonds were created by placing subprime mortgages into a trust and dividing the aggregate cash flows into tranches[9]. A typical subprime trust is usually composed of several thousand individual mortgages, typically around 3,000 to 5,000 mortgages for a total amount of approximately a billion dollars. The distribution of cash flows generated by the mortgage pool are tranched

[8] There is a large literature about security design, see Allen and Gale (1995).

[9] Subprime CDOs are in fact CDO squared on subprime mortgages.

into different classes of mortgage backed bonds, from the equity tranche, typically created through over-collateralization, to the most senior tranche rated triple-A. A typical subprime CDO has a pool of assets composed of mortgage backed bonds rated double-B to double-A, with an average rating of triple-B.

There was a chacteristic in the design that made the tranches quite sensitive to mortgage defaults. The problem was that the initial level of subordination for a triple-B bond was relatively small, between 3 and 5 percent and the width of the tranche was very thin 2.5 to 4 percent maximum. As prepayments occurred, the level of subordination of the lower tranches increased in relative terms over time. Assuming a recovery of 20 percent on the foreclosed homes, means that a default rate of 20 percent on subprime mortgages, which is realistic in the current environment, will most likely hit most of the triple-B tranches, causing default. The typical collateral pool of a CDO would normally contain bonds from different locations, giving geographic diverisfication. The premise being that down turns in local housing markets would be isolated events and the national market would continue to flourish.

The rolling over of subprime mortgages was dependent in large part on rising house prices, so that the borrower could refinance. The fall in house occurred in states right across the country. Compounding the severity of the problems was the recessionary economic environment. Under these circumstances, the loss correlations across all the mortgage backed bonds in the collateral pool will be close to one. As a consequence, if one mortgage backed bond is hit, it is most likely that most of the mortgage backed bond will be hit as well during the same period. And, given the thin width of the tranches, it is most likely that if one mortgage backed bond is wiped out, they all will be wiped out at the same time, wiping out the super-senior tranche of the subprime CDO.

In other word, we are in a binary situation where either the cumulative default rate of the subprime mortgages remains below the threshold that keeps the underlying mortgage backed bonds untouched and the super-senior tranches of subprime CDOs won't incur any loss, or the cumulative default rate breaches this threshold and the super-senior tranches of subprime CDOs could all be wiped out.

3.2 Market Disruptions

Special investment vehicles invested in long term assets and financed their purchase issuing asset backed commercial paper (ABCP). With the fall in house prices and increased uncertainty about the value of the underlying collateral, vehicles had to reduce the amount of

ABCP, forcing them to sell assets in order to meet claims. The uncertainty about collateral valuation increased, investors eventually refused to purchase new ABCP. The rating agencies had anticipated market disruptions and insisted that vehicles have multiple backstop lines of credit. What they had not anticipated was the effects of "wrong way" feedback. The valuation of the collateral became increasing difficult as the value of the vehicle's assets (mostly illiquid assets) declined. This triggered the selling of illiquid assets, causing further price declines.

If the ABCP paper had been issued with a clause stating that if the vehicle was unable to roll over its debt, the maturity of the paper could be extended one or two years, then this would have reduced some of the pressure on the hedge funds.

3.3 Summary

Both of these examples illustrate how design features affected the performance of instruments. For new innovations, the challenge is to identify the features in the design that affect its risk profile and the ability of investors to hedge.

4 Liquidity

With any new innovation there will initially be limited liquidity. Liquidity for an innovation depends on many factors, such as the ability to grow both the supply and demand, the ease of pricing the innovation, the transparency of the pricing process, the existence of hedging tools and the costs associated with hedging.[10] The ability to hedge and speculate makes an instrument attractive to a wide range of investors.[11] An innovation will attract certain types of investors on the demand and supply sides and the actions of these different groups affect the level and the stability of liquidity in the market. The participation in the market by some investors will be sensitive to macro-shocks. If the investors are forced to leave a market, unwinding positions will increase price volatility and adversely affect liquidity.

[10] The interaction between market and funding liquidity is discussed in Brunnermeier and Pedersen (2009).

[11] In the current credit crisis, some commentators have recommend that the purchase of credit default swaps be restricted to investors who own the underlying asset. This would greatly reduce the liquidity of the CDS market.

4.1 Education

With the launching of a new innovation comes the need to build both supply and demand by educating potential users about the usefulness of an innovation, its risk-return characteristics and identifying any accounting or regulatory issues that might impede adoption. The range of possible uses will affect the size of the supply and demand and thus the size of the group of investors willing to trade the instrument and thus its liquidity.

The complexity of an innovation also affects its appeal to different clienteles and the amount of education required to reach end users. A credit default swap is a simple contract to shift credit risk. It protects one party (the protection buyer) from the loss from par on a specified face value of bonds of a specified seniority following the default of the reference obligor specified in the contract. When these instruments were introduced, many institutions devoted much effort explaining the uses of the instruments, how they could be hedged and the general pricing methodology. In this case, many investors such as banks and fixed income portfolio managers found the innovation attractive, as it offered an alternative way to limit their exposure to default risk. A collateralized debt obligation (CDO) is a complex product. Each CDO has its own unique structure defining how cash flows from the underlying assets are allocated to the different tranches over the life of the instrument. The complexity of this class of instruments limits its appeal (at least in the ideal world[12]) to investors with the ability to analyze the risk profile and to understand the frailty of the underlying assumptions.[13]

To ensure liquidity, it is necessary to grow the supply side of the transaction. Depending on the type of innovation, there may be a natural clientele for which the product provides a convenient way to adjust their risk exposure. The supply side may grow if the risk-return characteristics of the innovation are attractive to investors and there are hedging instruments.

In any new form of financial instrument, there is the possibility of ambiguity in the contract terms and procedure, giving rise to legal and settlement risk. To minimize these costs, it is desirable that contracts become standardized, meaning that there is some form of master contract where the terms and procedures are unambiguously stated. The number of terms and procedures generally increases with the complexity of an instrument. The more complex an instrument, the more difficult it will be to develop a standardized form of contract. The benefits of adopting a standardized contact, such as an International Swap and Derivatives Association master agreement, is a lowering of transaction costs associated with legal and settlement risk and consequently is a major contributor to improving an

[12] From the recent credit crisis, it is clear that many investors failed to understand the risk chacteristics of these instruments.

[13] The issue of complexity is discussed in Rowe (2005).

instrument's liquidity.

4.2 The Ease of Pricing a New Product

Investors' ability to analyze and price a new product is directly affected by the nature of the assets underlying the product, the complexity of the design and the availability of data. If it is relatively easy to determine the price, this aids investors' understanding of the role different factors have upon price and helps to increase their confidence in the model prices and hence liquidity. The structure of an innovation plays an important role in the ease of pricing. If an innovation references a constant portfolio of underlying assets, then this reduces the costs of acquiring data and analysis. For example, a credit default swap references a bond type of a given seniority issued by a company. If the reference portfolio is complex and the structure of the innovation complex, as is the case for CDOs, then this greatly increases the data requirements and analytic skills needed to understand the complexity of the structure.

In some cases the data requirements can be formidable, as is the case for subprime backed bonds. Data on the subprime mortgages supporting the bonds may be difficult to access and the bonds are illiquid. This adversely affects the ability to price the instrument. Portfolios of these bonds are often used for securitization and their illiquidity compounds the difficulties of pricing mortgage backed CDOs. Data about CDOs can be purchased, though it is incomplete and not always timely. This contributes to the inability to reliably price these assets and hence liquidity.

For pricing we need to address both the data requirements, ability to calibrate models and the complexity of the innovation. For a CDO the only way to value this type of instrument is via Monte Carlo simulation.[14] But before the simulation can be performed, it is necessary to calibrate the model. This involves having to specify the marginal distributions for each of the underlying assets, describing the joint default dependency and the loss given default for each asset. However, without reliable prices for each of the underlying assets, each of these tasks becomes problematic. In a top-down approach prices of different tranches can be used for calibration. These are usually very illiquid. If calibration is not easy, this will be detrimental to liquidity, as it increases the uncertainty about the accuracy of the model price. In a bottom up approach, it is necessary to calibrate using prices of the underlying assets if such prices are available. Without prices of tranches, specification of default dependence is challenging.

[14] An alternative would be to use scenario analysis. For pricing it is necessary to specify the probability (under the pricing measure) of occurrence for each scenario.

For complex products, many investors do not have the in-house ability to address all the data issues and perform model valuation and have relied on credit ratings as guide for the inherent risk and what should be an acceptable price by comparing yields of instruments of similar risk. The credit rating has been used as a risk measure, even though it measures only one dimension of credit worthiness. The inability to readily analyze such structures increases the uncertainty about the valuation and decreases the liquidity of the bonds. However some investors have stepped into the valuation "fog" to engage in credit rating "arbitrage"[15].

4.3 Hedging a New Product

The existence of a secondary market provides investors with the ability to exit a position and this option directly affects the liquidity of the primary market. For a new product, the limited liquidity increases the risk in entering into a position and the costs of exiting the position. Many institutions recognize this and in order to grow the market, agree to make a secondary market on request. This exposes the institution to increased risk and also the investor, for while there may be a market allowing an investor to exit, the price may not be competitive.

For any position, the ability to hedge provides an avenue to reduce the risk exposure of a position. It also increases the attractiveness of investing in the innovation. For a new innovation, the task is to find other instruments that are natural hedging tools. The costs associated with hedging can be reduced if the characteristics of the innovation synchronize with the institutional features of the hedging instruments. A simple example would be that roll-over dates of the innovation match the maturity dates of the hedging instruments.

An innovation might be a catalyst for further innovations. If a bank sells credit protection using credit default swaps (CDS), it is exposed to two types of risk. If the credit worthiness of the reference entity underlying a CDS deteriorates, the bank will be forced to write down the value of the CDS and in the extreme case if default occurs the bank must compensate the protection buyer for the loss. One way for the bank to hedge this type of risk is to sell a portfolio of different CDSs to a special purpose vehicle and to buy protection of the *portfolio* of CDSs, creating what is called a synthetic CDO. This second form of innovation provides a way for the bank to hedge its risk and helps the supply of individual CDSs, improving liquidity.

[15] This refers to tranches with the same credit rating, trading with different yields. To quote one trader, "Pick the one with highest yield. It is a no brainer."

4.4 Transparency

New financial instruments trade in the over-the-counter market. Buyers and sellers must contact dealers to obtain bid/ask quotes and judge the depth of the market. The ability of investors to see posted bid/ask quotes on a regular basis of a third party screen helps to improve transparency of the pricing process, especially for less sophisticated investors. It also provides information about the depth of the market. In the fall of 2002, dealers in the CDS market realized this and agreed to trade an index on a portfolio of 125 investment grade obligors. Dealers posted bid/ask quotes daily on a third party screen. This greatly helped to improve the liquidity of the market. It allowed investors to take views on the market as a whole and also provided a means for them to calibrate their models.

4.5 Summary

In this section we identified some of the factors that determine liquidity for a new product. The process of building both demand and supply requires educating end users about the uses of a new product and its risk-return chacteristics and addressing any accounting and regulatory issues. The ease of pricing will depend on the complexity of the product and data availability. The ability to hedge will depend on what other instruments are available. The cost associated with hedging will depend on the compatibility of the innovation's design with respect to the institutional features of the hedging instruments. The ability to observe posted prices on a regular basis will provide investors with information about liquidity and market depth.

5 Counterparty Risk

Counterparty risk is the risk that a party to a contract might fail to perform, when called upon to honor its contractual commitments. It exposes the other party to the contract to a mark-to-market risk.[16] To determine the effects of counterparty risk on the value of a contract first requires identifying the nature of the counterparty risk. In some cases it could

[16] Consider the case of a credit default swap where there is the risk that the protection seller might default and for simplicity we assume there is no risk that the protection will default. If the protection seller defaults before the reference obligor, then to restore the protection buyer to the position prior to default necessitates pricing a swap with the same premium. If the credit worthiness of the reference obligor has deteriorated, then the value of the swap to the protection buyer would be positive, implying a mark-to-market loss. If the reference obligor defaults and the protection seller defaults prior to settlement, the protection buyer is exposed to the full loss from the reference obligor. See Turnbull (2005).

be default by the counterparty. In other cases it could be the risk of the counterparty being downgraded and its ability to post additional collateral.

If the underlying asset is a credit risky asset and the risk event for the counterparty is default risk, then to determine the impact of counterparty risk necessitates modeling the joint distribution of the default times for the underlying asset and the counterparty. If the underlying assets defaults first, the risk is whether the counterparty will default prior to settlement. If during the life of the contract the counterparty defaults first, it is necessary to price a new contract with the same premium.

The event of the counterparty defaulting will in general be affect the probability distribution of the reference asset subsequently defaulting.[17] Default by the counterparty can occur any time and Monte Carlo simulation is usually employed to model this process. When default occurs, it is necessary to price a new contract. For complex instruments such as CDOs, a separate simulation is required, implying that it is necessary to perform a simulation within a simulation. To ensure reasonable accuracy the total number of simulations becomes prohibitive implying that for complex instruments different types of approximations must be employed.[18]

5.1 Reducing Counterparty Exposure

Steps to mitigate counterparty risk span a wide spectrum, from limiting total exposure to individual counterparties, exposure to particular sectors, master contract agreements that facilitate netting, "haircuts" in pricing, posting of collateral and payment in advance. Some of these approaches are model independent. Limiting the total exposure to a particular obligor requires only information systems that can keep track of the total exposure to a particular obligor. For some types of instruments, this requirement may not be possible. For example, for synthetic CDOs, the same obligor may appear in many different traches. Standard and Poor's reported that just 35 different borrowers appear in nearly half of the 184 CLOs that it rates.[19] Unless the names of the obligors in the different assets are known, then it is impossible to determine the total exposure.

If there are already a number of contracts with the same counterparty that are covered under a master agreement, then the effects of counterparty risk on the valuation of contracts are non-linear. For example, let X and Y denote the value of two contracts to some investor I.

[17] See Gagliardini and Gourieroux (2003) for a detailed discussion.

[18] See Pykhtin (2005) for a survey of the different approaches that are used in practice.

[19] See Sakoul (2009).

These contracts have the same counterparty C. Without a master agreement, the exposure to counterparty C is

$$\max(0, X) + \max(0, Y)$$

With a master agreement, the exposure to counterparty C is

$$\max(0, X + Y)$$

but

$$\max(0, X + Y) \leq \max(0, X) + \max(0, Y) \tag{7}$$

implying that a master agreement lowers the exposure, as expected.

A new product will not be covered under a master agreement. Let Z denote the value of the innovation to investor I, the contract is with the same counterparty C. The exposure to counterparty C is given by

$$\max(0, X + Y) + \max(0, Z)$$

To lower counterparty risk, it is in the interest of dealers to attempt to standardize the contract as quickly as possible, so that contract can be covered under a master agreement - see expression (7).

One way to lower counterparty risk is for investors to clear trades in the innovation through a *clearing house*. The clearing house steps in and becomes the counterparty to the investor I. Note that the clearing house is exposed to investor I and the counterparty. A clearing house concentrates counterparty risk and requires careful risk management and adequate capital to prevent failure.

5.2 Implications for an Innovation

For a new innovation the difficulty of estimating the effects of counterparty risk are compounded due to the limited data and liquidity. First, there is limited information available to help in specifying the joint distribution describing the occurrence of the risk event for the counterparty and the reference asset. Second, for an new product, the financial institutions offering the product need to develop the necessary back office facilities to keep track of the counterparties associate with the product. Third, the financial institution needs to carefully consider whether there is wrong way dependence. The posting of collateral provides protection if the value of the collateral is not positively dependent on the same factors that affect the counterparty. If conditions in the economy adversely affect the credit worthiness of the counterparty and the value of the posted collateral, then it becomes necessary to increase the posted collateral. The posting of additional collateral may further weaken the credit worthiness of the counterparty.[20] It is important to recognize ex ante this form of "wrong way" dependence. Another issue is whether the collateral is traded in a liquid market. If not, then questions about the valuation of the collateral can arise, especially if there is "wrong way" dependence.

For a new innovation it is necessary to establish the legal identity of the counterparty and to know the judicial system governing any disputes with the contract. Different legal systems may accord different treatments for the contract.

5.3 Summary

In this section we have identified some of the additional issues that arise in assessing the effects of counterparty risk associated with innovations. First, data limitations make it challenging to estimate the joint distribution between the underlying asset and the counterparty; second, the need to develop the back office support; third, the need to recognize the possible existence of wrong-way dependence if collateral is posted; fourth, the need to standardize the contractual terms and develop a master agreement; and finally, the treatment of the contract under different legal systems.

6 Risk Management

Risk management entails being able to measure and manage risk over specified horizons.[21] To measure the risk at a specified horizon implies the ability to generate the probability distribution describing the value of an instrument or portfolio. There are two steps in this operation. First, the ability to price the instrument or portfolio at the horizon. This involves using the pricing ("risk-neutral") probability distribution. Second, to estimate risk measures such as value-at-risk or expected short fall, involves using the natural probability distribution. Risk management always involves using both the natural and "risk-neutral" probability distributions. To manage the risk profile means the ability to hedge risk exposures. This often involves calculating partial derivatives of the price with respect to certain variables

[20] In the current credit crisis, concern has been expressed about the consequences of AIG being downgraded and whether it had the ability to post collateral arising from all the contracts it had written.

[21] The limitations of traditional risk measures such as value-at-risk are well known and will not be discussed. See McNeil, Frey and Embrechts (2005).

(the so-called "Greeks") to construct a hedge. If the pricing model is misspecified, then the partial derivatives will be misspecified and hedging will be ineffective.

To risk manage a new financial innovation necessitates identifying the different dimensions of risk associated with the innovation. The usual starting point is pricing of the instrument, which raises the following questions. What type of model to use? Does data exist that facilitates the estimation or calibration of the model's parameters? How sensitive is the pricing to certain parameters? How effective is the model for hedging? What are the costs associated with hedging? There are many additional dimensions to risk that are difficult to quantify. We call these hidden dimensions *dark risk*. For example, what is the best way to address the estimation of model parameters in a non stationary environment, given limited data? How does the complexity of an instrument and parameter uncertainty affect the pricing and risk management?[22] Are there legal and/or settlement risks associated with the contract? Is there any way to test the model?

There are other dimensions of dark risk arising from managerial considerations. The first issue is understanding how an accounting system can generate incentives for traders to undertake trades, where the prime purpose of the trades is to enhance their bonuses. In an environment where there is a constant flux of innovations, senior management is often ignorant of the exact nature of the innovations. This affects their ability to judge the risk characteristics and to understand all the costs that an innovation generates.

6.1 Model Parameters

Data availability influences the choice of model. If data are limited, this restricts the types of models that can be employed, given that it is necessary to calibrate the model. This implies that the model can not be too sophisticated. Typically a methodology that can be calibrated and used for products that depend on a subset of the factors that affect the new innovation is modified so that it can be applied to the new innovation. This usually necessitates additional assumptions. For example, the issue of modeling default dependence is addressed in risk management in order to meet the requirements of Basle II. A similar type of modeling approach is used to price multi-name credit derivatives, though the calibration procedures are quite different. Without sufficient data, time series analysis of the properties of the price dynamics is limited. This also implies that the ability to test the model will be limited.

For pricing, a model is usually calibrated to match extant prices. For new innovations,

[22] Some of these issues are discussed by Rowe (2009).

markets are illiquid and the spread due to the lack of liquidity is incorporated into the parameters of the pricing model. Implicitly it is assumed that the determinants of the liquidity in the market are the same as the determinants of the value of the innovation. There is no reason why this should be the case. However, without a model to describe how liquidity varies, the modeler has no choice but to compound the determinants of liquidity and value. This increases the variability of the parameter estimates.

A typical pricing or risk management model takes a number of inputs and estimated parameters to produce an estimate of either a price or a risk measure. There may be certain input and parameters that can cause significant changes in the output. For example, in stock option models uncertainty about the volatility can have a first order effect on price. For multi-name credit derivatives specification of the default dependency can significantly affect both the price and risk measures. Knowledge about these types of sensitivities can provide important information to risk managers for stress testing. However, it is important to remember that stress testing assumes the validity of the underlying model and simply stresses the variables in the model. If the model is deficient, the risk manager may have a false sense of security.

6.2 Testing a Model

Any form of model should be tested for accuracy. If a model's parameters are calibrated so that the model matches existing prices on a particular day, as is standard practice, the issue is whether the model is useful for hedging. Many models can match price though do a poor job hedging, implying that they are misspecified and of limited value for risk management. The issue of judging the hedging performance of a model, even when there is adequate data available, is not straightforward. Hedging is performed in discrete time and is subject to bid/ask spread issues and hence the hedging errors will be described by a distribution that has a finite non-zero mean.[23] To judge the relative performance of model specifications is equivalent to judging between different distributions. This can be done, given additional assumptions. With limited data, such an exercise is problematic.

If there is an absence of establishing a way to judge a model for a new innovation, we can still perform some useful risk management exercises, though it does require risk managers to think about all of the possible factors that might affect risk and not simply those used in their risk models. For example, consider a CDO on residential mortgage bonds. Each

[23] In continuous time and zero bid/ask spread, the pricing error should be zero if the model is correctly specified.

bond is written on a portfolio of residential mortgages. The bonds are chosen from different geographic areas in order to increase the level of diversification. The correlation of residential mortgage default rates across states has typically been quite low in an environment of rising house prices. We know that these bonds are related to both economy wide and regional factors, implying default dependence can vary with the state of the economy. At the start of 2006 the rate of increase in house prices started to decrease across many major states. The U.S. car industry has been experiencing troubles for many years and with rising gasoline prices the demand for automobiles would decrease, causing further economic difficulties for the U.S. car industry and associated suppliers. These types of considerations raise questions of how the risk of the CDO would be affected if (1) there is an increase in mortgage default rates and (2) an increase in the default dependency across states. However, the ability of the risk manager to ask such questions requires an environment that encourages managers to think about the risk drivers and how changing conditions affect the relative importance of the drivers and the overall risk. These broader considerations can not be achieved by simply relying on mechanical stress testing of models.

There are other dimensions of risk that are usually not mentioned in discussions about risk management, yet can have major impact on the risk associated with an innovation. For example, the availability of hedging instruments and the ease of hedging. The risk manager needs to identify how the ability to hedge varies with the state of the economy. Second, certain instruments may require the posting of collateral, depending on the risk of the underlying reference entity and/or the credit worthiness of the writer of the contract. The conditions triggering the collateral calls and the determination of the amounts need to be easily identified. Both for pricing and risk management, it is necessary to estimate the probability of a call and the additional amount of collateral. Another example would be an innovation that requires the rolling over of short term debt. The lender of the debt may require collateral of a certain value. The risk is how the value of the collateral and the innovation are related. If the value of the collateral decrease, it is may become necessary to post additional collateral lowering the value of the innovation. In the extreme case the market may cease to function, implying that it is impossible to rolled over the debt. This form of "wrong way" dependence poses a major risk. The role of the risk manager is to recognize it existence, identify the consequences and assign a probability of occurrence as conditions change. For a new innovation it is essential to identify these considerations in order to understand the risk of the innovation in changing economic conditions.

6.3 Unintended Consequences

The introduction of a new innovation may generate a series of unintended consequences. For example, the introduction of subprime mortgage backed CDOs was initially profitable for the issuers. This created a demand for these types of mortgages. To ensure an adequate supply, originators lowered their underwriting standards, as they were rewarded on the basis of volume and shifted the risk of mortgage defaults to the arrangers (the issuers of the CDOs).[24] This lowering of underwriting standards increased the probability of default for the mortgages contained in mortgaged backed bonds. Given the use of historical data, this change was not reflected in the data used to model the risk of the CDOs. A risk manager needs to look not just an innovation in isolation, but the incentives facing different players that contribute to the innovation and the consequences of the incentives.

The risk manager also needs to recognize that holding different examples of an innovation may result in a concentration of risk. For example, holding different types of mortgage backed CDOs, may result in a concentration of risk if the same bond appears in different CDOs. Standard and Poor's reports that just 35 different borrowers appear in nearly half of the 184 collateralized loan obligations that it rates. The risk manager needs the ability to identify the underlying assets in an innovation. This means that the data about the underlying assets must be available.

6.4 Accounting Incentives

When an innovation is introduced, often an existing accounting framework for another security is adopted to account for trades in the innovation. Traders would be familiar with the characteristics of the accounting scheme and "fit" the new product into the existing framework. Traders' incentives are inherently short term in nature, given the typical way of determining bonuses that concentrate on the profits generated over the accounting year. They have incentives to engage in trading activities that generate profits over the short run at the expense of long term profits. In the long run they may not be employed by the same institution, or they hope to offset future losses.

The challenge for risk managers is to understand the incentives generated by the accounting system and the types of trades that it encourages traders to undertake. Risk managers must try to distinguish between trades that generate short run profits and those that are in the best interest of the firm. Risk managers face another obstacle, that of ignorance on the

[24] For a more detailed analysis of the associated incentives, see Crouhy, Jarrow and Turnbull (2008).

part of senior management.

6.5 Senior Management

When an innovation is introduced, senior management may not understand the nature of the innovation, its risk chacteristics and how the accounting treatment fits the innovation and the incentives generated by the accounting system. They often refuse to acknowledge their ignorance and rely on the traders and their quants to characterize the profitability and risk.[25] However, the incentives of the trading desk are usually not aligned with those of senior management. Traders are rewarded on the basis of the profitability of their desk over the accounting year, while senior management are rewarded on the basis of their business. Bonuses are paid in the form of cash and deferred shares, vested over a few years. If the cash part is large enough and the vesting period short enough, then the long run is relatively unimportant for traders.

Diligent risk managers may object to certain trades on the grounds that they are not in the best interests of the firm, being driven by the desire to increase bonuses. For their objections to be enforced, requires support by senior management. Risk managers are unlikely to receive support if senior management is ignorant and do not understand the issues, relying on the traders and quants for guidance.[26] Regulators are often in the same position as senior management. They have far less incentives than senior management to understand the complexities and subtleties of an innovation. Hence, they fail to provide risk managers with the necessary support.

6.6 Mark-to-Model

In recording the value of an illiquid asset, a model price is usually used. We have already discussed the issues arising from calibration. Here we focus on some of the additional costs and risks that are usually neglected when determining the value of an innovation. For an innovation there are greater operational risk than associated with a seasoned product. The list is long and includes such issues as the accounting incentives generated by the accounting system, model risk, complexity risk (the more complex a product the greater is the risk of pricing and trading errors), settlement risk and legal risk.[27] To determine the value of an

[25] Arrogance and ignorance were the prime drivers behind the collapse of Barings Bank in 1995. See the Report of the Board of Banking Supervision.

[26] The role of risk managers versus traders is discussed in Blankfein (2009).

[27] A good introduction to operational risk is given in Crouhy, Galai and Mark (2001, chapter 13).

innovation these operational costs should be included.

6.7 Summary

In this section we have discussed some of the many additional problems that an innovation causes in risk management. Given data and model limitations, risk managers need to take a broader view of risk determinants. They also need to consider whether an innovation generates perverse incentives to different players and the resulting consequences.

7 Credit Rating Agencies

For certain types of instruments a credit rating is often a prerequisite in order to increase the marketability of the innovation. The determination of a rating for an innovation typically involves detailed discussion between the issuer of the innovation and the credit rating agency about the methodology and the availability of data the agency will employ to determine a rating. This is often an interactive process, resulting in refinements of the instrument to ensure appropriate ratings. The assessment of a rating may involve both quantitative and qualitative considerations.

For a risk manager or investors not involved in these issuer/rater discussions, the methodology used to determine the ratings is not transparent. The rating agencies publish much general information about their methodologies. However, precise information does not appear to be available. For risk managers and investors, transparency in the rating process is necessary in order to understand how a rating is defined, the methodology and the type of data used.

7.1 Understanding a Rating

The first requirement is to understand what criteria a rating agency is using as a measure of credit worthiness. A rating scheme is an ordinal ranking: an instrument with a triple A rating has in some sense less credit risk than an instrument with a double A rating. A rating may be either an assessment of a probability of a defined event occurring or the expected loss if the defined event occurs. Given a particular definition, the agency may assign the quantitative part of the rating based on some form of average rating over some horizon, to give a "through the cycle" assignment. How the average is computed is not clear. How the qualitative part is assigned is unclear and how the quantitative and qualitative parts are combined is also unclear.

A credit rating does not describe the risk of an asset.[28] The value of an asset may change due to changes in its credit worthiness without any change in the credit rating, even with continuous monitoring. Rating agencies do not continuously monitor assets, so the changes in valuation can be more severe. There are at least two reasons for this. First, for any credit rating there is a range of credit assessment values within the rating. Movements of credit worthiness within this range can occur without a change in rating. Second, a rating is some form of time average of the credit worthiness of the asset over the life of the contract. The rating over estimates the credit worthiness in bad times and under estimates in good times. A rating measures one aspect of credit risk. Investors and risk managers need to understand the different factors that affect the value of an innovation and its credit worthiness.

The second requirement is to understand the methodology. This necessitates identifying the factors that affect the credit worthiness of the innovation and matching this list against the factors that have been considered in the rating assessment. In the recent credit crisis, investors learnt that the valuation of collateral assets was not considered in assessing the rating of a special investment vehicle. Knowledge about the methodology allows the identification of the model assumptions and the opportunity to examine their robustness. However, the ability to test or judge robustness requires knowledge about the market. This may be missing for new innovations, implying that risk managers will have to rely on professional judgment.

The third requirement is to know the type of data employed when determining a rating. In the recent credit crisis the rating agencies accepted the data from the originators, without doing any form of checking about whether distributional assumptions had changed. They ignored information about the increasing misrepresentation of borrower characteristics. The nature of the data greatly influences the distributional assumptions. Is a long time series necessary for estimation? What assumptions are made about the stationarity of the coefficients? Is there enough empirical evidence to justify the assumed distributional assumptions? Without sufficient data, it is difficult to test the robustness of assumptions.

[28] A credit rating is not a sufficient statistic for measuring the risk of an asset - see Brennan, Hein and Poon (2009) and Crouhy, Turnbull and Wakeman (1999).

7.2 Implications

For innovations, data availability and the nature of the distributional assumptions are important issues that must be addressed in order to estimate different risk measures over arbitrary horizons. In the absence of sufficient data about the innovation, data pertaining to the underlying assets in a structure may be available and can be used to extract information about the range of parameters used to measure the risk of the innovation. Often the availability of this data is limited. For synthetic collateralized debt obligations, the underlying assets are credit default swaps. The market for these assets has only been in existence for a relatively short period, making it difficult to infer behavior in different economic conditions. Consequently, much professional judgment must be used is specifying the assumptions with respect to the probabilities of default, default dependence and recovery rates, when trying to assess the credit worthiness of a structure.

For risk managers and investors the challenge is to interpret what information a rating actually conveys. Consider a rating on a mezzanine tranche of a mortgage backed CDO. For risk managers a useful risk measure would be the expected loss for each tranche over each year spanning the maturity of the structure. Presumably, a rating is an assessment of the average expected loss over the life of the CDO. The pattern of expected losses may fluctuate over the life of the contract. By using some form of average, information about the fluctuations is suppressed, yet information about fluctuations would be of benefit.

7.3 What Use Is a Rating?

Given the limitations of credit ratings, how can risk managers use ratings in risk management? In CreditMetics bonds and loans are allocated to credit risk classes and the change in credit quality over a one year horizon is modeled by using the transition matrix describing the probabilities of rating transitions. In this approach all bonds within a rating class are treated as homogeneous. If a new innovation can be classified as having the same credit risk characteristics as an existing instrument, then this might provide a way to use the same risk management tools. If this is not the case, the challenge is to determine how ratings can be usefully employed.

Risk managers also need to consider whether conflicts of interest that rating agencies face have affected their objectivity, especially as rating agencies have little legal exposure, given their use of a First Amendment defence - see Coffee (2008).[29] Without independent verifi-

[29] The rating of credit structures has been a very profitable business for the rating agencies. Moody's

cation, investors face a "market for lemons" situation: the rating is probably too generous. The rating agencies publish tables detailing how different rating classes for bonds and loans have performed with respect to their credit performance. For bonds and loan the agencies have data extending back many decades. This is not the case for structural products. These products necessitate modeling the cash flows generated by the assets in the collateral pool. This means that it is necessary to model default dependence. Until recently there is little empirical information about the performance of the agencies' models. For a new innovation the rating methodology is untested. Risk managers and investors need to remember the tentative nature of the methodology.

7.4 Summary

In this section we have discussed some of the issues that arise in the use of credit ratings for innovations. For investors and risk managers, the first issue is determining what is the precise meaning of a rating. Next, is understanding the methodology behind the quantitative and qualitative aspects of a rating and the data requirements. Finally, is the issue that for an innovation the rating methodology is tentative and untested, implying that whatever information a rating conveys should be treated with caution.

8 Conclusions

In this paper we have discussed some of the diverse reasons that generate the challenges of measuring and managing risk of innovative financial products. To measure risk requires the ability to first identify the different dimensions of risk that an innovation introduces. The list of possible factors is long: model restrictions, illiquidity, limited ability to test models, design characteristics, counterparty risk and managerial related issues. For measuring some of the different dimensions of risk, the implications of limited available data must be addressed. Given the uncertainty about model valuation and estimated risk metrics, how can risk managers respond? Stress testing a model of unknown validity may generate a false sense of security. For scenario analysis to be useful, risk managers need to understand the different factors that affect the product. This requires the ability to think outside the confines of their limited pricing models, something that was missing in the current credit crisis. The use of credit ratings for an innovation is problematic for two reasons. First, the meaning of a rating is unclear and second, the rating agencies are faced with the same data

reported in 2006 that 43 percent of total revenues came from rating structured products.

and measurement issues, implying that any credit risk measure should be treated with great caution. All parties within a company - senior management, traders and risk managers - have important roles to play in assessing, measuring and managing risk of new products. The company's directors also have a responsibility to ensure that these duties are being fulfilled.

The problems facing regulators following the introduction of an innovation range from the problems with an individual institution to systemic effects. In the current credit crisis regulators placed (and continue to place) too much faith in rating agencies. For an innovation, a rating is a rough measure of some poorly defined credit metric. Regulators need to question about whether ratings should be used for innovations in determining capital. For innovations, especially complex products such as collateralized debt obligations, detailed information about an innovation has often not been available to investors. Regulators can require that data about each innovation be available to investors and regulators on a timely basis. This would allow independent testing. To measure systemic risk, all major institutions including hedge funds need to come under regulatory monitoring. Regulators need the ability to measure the holding of an innovation by different institutions and the build up of concentrated holdings.

References

[1] Acharya, V. S. Bharath and A. Srinivasan (2003). "Understanding the recovery rates on defaulted securities". WP London Business School.

[2] Allen, F. and D. Gale. *Financial Innovation and Risk Sharing*, Second Edition, M.I.T. Press, Cambridge, Massachusetts.

[3] Altman, E. A. Resti and A. Sironi (2005). "Default recover rates in credit modeling: a review of the literature and empirical evidence", *Journal of Finance Literature*, 21-45.

[4] Andersen, L. (2006/7). "Portfolio losses in factor models: term structures and intertemporal loss dependence", *Journal of Credit Risk*, 2, 4, 3-31.

[5] Blankfein, L. (2009). "Do not destroy the essential catalyst of risk", Financial Times (London).

[6] Brennan, M. J., J. Hein and S-H Poon (2009). "Tranching and ratings", WP, Anderson School, UCLA.

[7] Brunnermeier, M. K., and L. H. Pedersen (2009). Market liquidity and funding liquidity", forthcoming *Review of Financial Studies*.

[8] Burtschell, X. J. Gregory and J-P. Laurent (April 2005). "A comparative analysis of CDO pricing models", WP, BNP-Paribas.

[9] Coffee, J. C. (April 22, 2008). "Turmoil in the U.S. credit markets: the role of the credit rating agencies", Testimony before the United States Senate Committee on Banking, Housing and Urban Affairs.

[10] Crouhy, M. D. Galai and R. Mark (2001). *Risk Management*, McGraw Hill, New York.

[11] Crouhy, M. G., R. A. Jarrow and S. M. Turnbull (Fall 2008). "Insights and analysis of current events: the subprime credit crisis of 2007", *Journal of Derivatives*, 16, 1, 81-110.

[12] Crouhy, M., S.M. Turnbull, and L. Wakeman, "Measuring risk adjusted performance," 1999, *Journal of Risk*, 2, 1, 5-35.

[13] Dai, Q., K. J. Singleton and W. Yang (2007). "Regime shifts in a dynamic term structure model of U.S. Treasury bond yields", *Review of Financial Studies*, 20, 5, 1669-1706.

[14] Duffie, K. and K. Singleton (1999). "Modeling term structures of defaultable bonds", *Review of Financial Studies*, 12, 687-720.

[15] Dullmann, K. and M. Trapp (2004). "Systematic risk in recovery rates - an empirical analysis of U.S. corporate credit exposure". WP Deutsche Bunderbank, Frankfurt, Germany.

[16] Eberlein, E. and F. Ozkan (2003). "The defaultable Lévy term structure: rating and restructuring", *Mathematical Finance*, 13, 277-300.

[17] Eberlein E. W. Kluge and P. Schönbucher (Summer 2006). "The Lévy LIBOR model with default risk", *Journal of Credit Risk*, 2, 3, 3-42.

[18] Gagliardini, P. and C. Gourieroux (August 2003). "Spread term structure and default correlation", WP, Lugano and University of Toronto.

[19] R. A. Jarrow and S.M. Turnbull, (March 1995). "The pricing and hedging of options on financial securities subject to credit risk", *Journal of Finance*, 50, 1 , 53-85.

[20] Jarrow, R. A. and F. Yu (2001). "Counterparty risk and the pricing of defaultable securities", *Journal of Finance*, 56, 5, 555-576.

[21] Lando, D. (1994). Three Essays on Contingent Claims Pricing, Ph. D. thesis, Cornell University.

[22] Lando, D. (1994). On Cox processes on credit risky securities, *Review of Derivatives Research*, 2, 99120.

[23] Li, D. (2000). On default correlation: a copula function approach", *Journal of Fixed Income*, 9, 1, 43-51.

[24] Longstaff, F. A. and A. Rajan (2008). "An empirical analysis of the pricing of collateralized debt obligations", *Journal of Finance*, 63, 2, 529-563.

[25] Merton, R. C. (1974). "On the pricing of corporate debt: the risk structure of interest rates", *Journal of Finance*, 29, 449-470.

[26] McNeil, A. J., R. Frey and P. Embrechts (2005). *Quantitative Risk Management*, Princeton University Press, New Jersey.

[27] O'Kane, D. (2008). *Modelling Single Name and Multi-name Credit Derivatives*, Wiley, New Jersey.

[28] Protter, P. (1993). *Stochastic Integration and Differential Equations*, Second Edition, Springer: New York.

[29] Pykhtin, M. (2005). *Counterparty Credit Risk Modelling*, Risk Book, London.

[30] Report of the Board of Banking Supervision, *Inquiry into the Circumstances of the Collapse of Barings*, (1995), Bank of England.

[31] Rowe, D. (2005). "The danger of complexity", Risk, (April), 91.

[32] Rowe, D. (2009). "Second-order uncertainty", Risk, (March), 91.

[33] Sakoul, A. (2009). "S&P sees new systemic risk in CLO defaults", Financial Times (London).

[34] Schönbucher, P. J. (2003). *Credit Derivatives Pricing Model*, Wiley, New Jersey.

[35] Schönbucher, P. J. and D. Schubert (2001). "Copula dependent default risk in intensity model", WP, Department of Mathematics, University of Bonn.

[36] Turnbull, S. M. (2005). "The pricing implications of counterparty risk for non-linear credit products", *Journal of Credit Risk*, 1, 4, 3-30.

[37] Yu, F. (2007). "Correlated defaults in intensity based models", *Mathematical Finance*, 17, 155-173.