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An Empirical Study of Credit Default Swaps

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Abstract

We examine the pricing of Asian and non-Asian credit default swaps that traded during the 1997 to 1999 time period. We employ two credit risk models, Duffie and Singleton (1999) and Jarrow and Turnbull (1995). We argue that credit default swaps should have a positive economic value since credit spreads reflect differences in liquidity as well as credit risk. However, in the presence of moral hazard we expect to see negative economic values since asymmetric information would motivate sellers of credit default swaps to demand a “restructuring premium”. While we generally find positive economic values for credit default swaps, both models find negative economic values for Asian credit default swaps during the recent Asian currency crisis, which we attribute to moral hazard.

JEL Classification: *G13, G22, G24*

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An Empirical Study of Credit Default Swaps

Many credit risk models have been proposed in recent years. However there are few studies that examine the empirical results from these models in pricing market traded credit derivatives. This paper addresses this gap by implementing binomial versions of Duffie and Singleton (1999) and Jarrow and Turnbull (1995) and applying them to price credit default swap contracts.

We make three contributions. First, as far as we are able to determine we are the first to empirically examine the pricing of credit default swaps, an important instrument in the developing over the counter credit derivatives market. Second, we examine the empirical performance of the “return of market value” and the “return of Treasury “ recovery assumptions that underlie the difference between the Duffie and Singleton (1999) and Jarrow and Turnbull (1995) credit risk models. Finally, by appealing to basic financial theory, we develop a methodology to estimate a yield curve that is subject to credit risk by calibration. This allows us to estimate a below investment grade yield curve that is applicable for the pricing of a particular credit default swap, thereby resolving an important empirical problem.

We find negative economic values from the credit protection buyer’s point of view for credit default swaps written on bonds subject to the recent Asian currency crisis. In contrast credit default swaps not subject to the Asian currency crisis generally have positive economic values. We speculate that these results are evidence of the moral hazard problem that practitioners claim exists when payments from the credit default swap maybe triggered by bond restructuring as well as default.¹

We find that Jarrow and Turnbull (1995) returns lower premium values and default payment values from credit default swaps than those found by Duffie and Singleton (1999). This happens because Jarrow and Turnbull (1995) obtain higher hazard rates than Duffie and Singleton (1999) given the same information set concerning a particular credit

default swap. This confirms the numerical analysis of Delianedis and Lagnado (2002), but with market traded information.

An important barrier to empirical research in credit risk is the lack of precise information concerning the credit risky yield curve applicable to a given credit default swap. Helwege and Turner (1999) find that for bonds rated below investment grade, credit ratings are not precise enough to discriminate among bonds of different credit quality. Yield curves estimated for below investment grade bonds tend to be downward sloping, not because of any “crisis at maturity” problem, but because longer-term bonds rated below investment grade are more credit worthy than shorter-term bonds of the same credit rating. They show that once constructed from paired short and long term bonds from the same firm, below investment grade yield curves tend to be upward rather than downward sloping. This suggests that applying say a generic BB yield curve in an attempt to value a credit default swap written on a BB bond may lead to important bias.

We overcome this problem in the following way. In the absence of market frictions, MMI says that value additivity must hold so the value of the credit risky coupon bond underlying the credit default swap contract is simply the sum of the present value of its component cash flows. In other words, a coupon bond is a portfolio of zero coupon bonds where each zero coupon corresponds to a coupon or redemption payment and the sum of the values of these zeros must equal the value of the bond. In theory, the structure of credit risky zero coupon interest rates generated by a candidate credit risk model should replicate the market price of coupon bonds exactly. If not, then this implies that value additivity does not hold because the coupon bond, being composed of a portfolio of zeros, is worth less (more) than the addition of values of component zeros. This presents a pure arbitrage opportunity to market participants who should then buy (sell) the undervalued (overvalued) coupon bond and sell (buy) the portfolio of zeros by (reverse) coupon stripping the coupon bond. Hence pure arbitrage will force value additivity to hold.

This means we have a check on the reasonableness of our estimate of the corporate yield curve. First we calibrate a given credit risk model to an initial estimate of the credit

spread defined as the difference between our initial estimate of the yield curve that is subject to credit risk and an exogenously supplied Treasury yield curve. The structure of zero coupon interest rates generated by the calibrated candidate credit risk model is then used to price the bond. If the credit risk model overprices (underprices) the underlying credit risky coupon bond relative to the known market determined bond price, we add (subtract) a few basis points to (from) the yield curve that is subject to credit risk. We recalibrate the candidate credit risk model to this adjusted credit spread to obtain a new price for the credit risky coupon bond. We compare this price to the known market price of the bond and if they are not equal, we adjust the spread as outlined above once more. We continue to make adjustments to the credit spread until the candidate model replicates the value of the observed market price of the credit risky bond that underlies the credit default swap contract. Therefore we are able to obtain a reasonable estimate of the credit risky yield curve by ensuring that our estimate of the credit spread is consistent with value additivity. A reasonable estimate of the credit risky yield curve is important because the credit default swap is priced relative to this yield curve.

This paper is organized as follows. In the first section we will discuss the literature in general and Duffie and Singleton (1999) and Jarrow and Turnbull (1995) in particular. In the second section we will discuss how we implement these models by describing the data sources and the empirical procedures we employ. In the third section we present and discuss the empirical results. Finally we summarize our results and present our conclusions in section four.

IA General Literature Review

Proposed models of credit risk can be classified into two basic categories, structural models and reduced form models. The structural model views bonds subject to credit risk as options written on the value of an underlying firm's assets, such as Merton (1974), Chance (1990), Longstaff and Schwartz (1995), Leland and Toft (1996) and Saa-Requejo and Santa- Clara (1999). However, use of this approach requires information difficult to obtain since large portions of a firm's assets do not trade².

In contrast reduced form models use only market determined prices or parameters that can be estimated. This occurs because reduced form models assume default is a result of some exogenous process and so does not require estimates of the value of the firm's assets. A variation of these reduced form models is implemented by calibrating at least one unknown parameter to assure that the model replicates an exogenously supplied credit spread. This is an important empirical advantage since it relieves the empiricist from estimating or supplying at least one parameter. This is the reason why we focus on this type of model in this study.

The reduced form models can be further sub-divided into transition matrix and default models. Transition matrix models attempt to model the recovery process such that there are a series of stages a bond would pass through before the bond reaches the absorbing default state. In contrast, default is instantaneous in the default models. Examples of the former are Das and Tufano (1996), Jarrow, Lando and Turnbull (1997) and Schönbucher (1998) who concentrate on extending the reduced form approach by modeling the recovery rate. Das and Tufano (1996) and Jarrow, Lando and Turnbull (1997) model the recovery rate as a Markovian chain with as many states as credit classes while Schönbucher (1998) allows for multiple defaults.

Default models such as Jarrow and Turnbull (1995), Das and Sundaram (1998), Duffie and Singleton (1999) and Collin-Dufresne and Solnik (2001) develop more simple models where the bond either survives and pays whatever has been promised or defaults and pays a recovery amount. Jarrow and Turnbull (1995) assume recoveries in the event of default are a constant fraction of a Treasury zero. They solve for the hazard rate (pseudoprobability of default) by calibrating this parameter to guarantee that the model replicates an exogenously supplied credit spread. Das and Sundaram (1998) extract values of the recovery and hazard rates jointly from a bivariate model of the credit spread through use of a logit procedure. This procedure requires a time series of term structures to implement. Finally Duffie and Singleton (1999) model the credit risky interest rate as the default free interest rate plus a term that jointly adjusts for the hazard and recovery

rates. This simplification is possible because they assume that recoveries in the event of default are a fraction of the “survival contingent” value of a credit risky bond. This simplification allows one to model credit risky interest rates in the same way that we currently model credit risk free interest rates and reduces considerably the computational burden of implementing reduced form credit risk models. Collin-Dufresne and Solnik (2001) develop a multifactor reduced form default model that uses information in the swap term structure to explain the LIBOR-swap spread.

Recently hybrid models have been proposed that promise to combine the conceptual insights offered by structural models with the tractability of reduced form models. Zhou (1997) places a reduced form jump diffusion process for the value of the firm and Madan and Unal (1998) employ a two factor reduced form process that allows the value of equity to fall to zero once the sum of the value of interest insensitive cash assets and interest sensitive assets is less than the value of interest sensitive liabilities.

IB The Models

Our objective is to price credit default swaps. Since credit default swaps are American style options, there is no known closed form solution. Consequently we chose a binomial lattice implementation. We chose Duffie and Singleton (1999) and Jarrow and Turnbull (1995) because we wish to explore the choice between the “return of market value” (RM) and the “return of Treasury” (RT) recovery assumptions that is respectively employed by these two models. We first obtain a general expression that is applicable for all defaultable claims and then fill in this shell with Jarrow and Turnbull (1995) and then Duffie and Singleton (1999) to highlight the importance of the different recovery assumptions.

Under the risk-neutral probability measure Q conditional upon information available up to date t , Duffie and Singleton (1999) show that the price of a one period defaultable zero is written as,

$$V_t = E_t^Q \left[h_t e^{-r_t} \delta_{t+1} + (1 - h_t) e^{-r_t} V_{t+1} \right] \quad (1)$$

Note that h_t is the conditional (upon no prior default) hazard probability and r_t is the pure (credit risk free) interest rate at time t . Meanwhile δ_{t+1} is the recovery rate and V_{t+1} is the promised payoff of \$1 at maturity $t+1$. In other words a defaultable zero promises to pay V_{t+1} at maturity $t+1$, but the promise may be broken at hazard rate h_t . If default occurs with hazard rate h_t at time t , an amount δ_{t+1} is paid at time $t+1$, conditional upon no prior default. Then, under the risk-neutral probability measure Q , this future expected cash flow is discounted by the pure rate of interest.

The above is a general expression for the value of a one period defaultable zero. Nested within it are the Duffie and Singleton (1999) and Jarrow and Turnbull (1995) models. To highlight the differences among these models and the challenges confronted when modeling credit risk, we re-write (1) in state price format in the case of a two period defaultable zero. We assume the existence of the risk neutral probability measure.³

$$V_t = \{h(t, j) \delta_{t+1} + 0.5[e^{r(t+1, i+1)} + e^{r(t+1, i)}] + [1 - h(t, j)]\{0.5[h(t+1, j+1) + h(t+1, j)] \delta_{t+2} + [1 - 0.5\{h(t+1, j+1) + h(t+1, j)\}] V_{t+2}\} e^{-r(t, i)} + 0.5[e^{-r(t+1, i+1)} + e^{-r(t+1, i)}] \quad (2)$$

The above expression says that a defaultable zero may default during the first period with hazard rate $h(t, j)$ and recover δ_{t+1} at the end of the first period. The amount is reinvested in a Treasury security to earn the evolving stochastic Treasury interest rate until promised maturity. If the defaultable zero survives the first period with probability $[1 - h(t, j)]$, it may default at maturity in a high credit risk (high hazard rate) state with hazard rate $h(t+1, j+1)$, or it may default at maturity in a low credit risk (low hazard rate) state with hazard rate $h(t+1, j)$. If the zero defaults during the second period, investors recover δ_{t+2} at maturity. The corporate zero pays the promised \$1 (V_{t+2}) at maturity conditional upon

survival for both periods. All potential cash flows, both the terminal payoff and recovery amounts, are discounted back to the present using binomial stochastic pure interest rates.

Note that (2) explicitly recognizes that prior to maturity recovery amounts δ are reinvested in a Treasury security for the remaining maturity of the zero. This is necessary as (1) and (2) implicitly assumes that the investor is choosing (under the risk neutral probability measure) between a credit riskless and credit risky zero, and this reinvestment assumption ensures that the time horizon of the alternatives are consistent.

Two challenges are evident in (2). First, what is the relationship between hazard probabilities $h(t,j)$ that evolve in credit risk state j and pure rates of interest $r(t, i)$ that evolve in interest rate state i ? Second, hazard probabilities are conditional probabilities in that in order to default at t_2 , the bond must survive t_1 . This means that in all possible credit risky states j and interest rate states i , one must measure expected conditional payoffs in the event of default under the risk neutral probability measure for not only the current period, but also all possible prior periods. This requires a considerable computing effort. While both models discussed here deal with these challenges, Jarrow and Turnbull (1995) focus on the first challenge while Duffie and Singleton (1999) focus on the second.

It is tempting to solve the first challenge by “brute force”, that is calculate all possible hazard and pure interest state prices for all time periods. However this would be computationally expensive. The number of pure interest rate states will equal $t+1$, and the number of hazard states will be $t+1$ and all possible combinations will be $(t+1)^2$. Consequently, Jarrow and Turnbull (1995) and Duffie and Singleton (1999) impose distributional assumptions regarding the relationship between hazard and pure interest rates.

We now obtain a general binomial version of the Jarrow and Turnbull (1995) model from (2). A case of this result will be Duffie and Singleton (1999). By examining how the binomial version of Jarrow and Turnbull (1995) is transformed as we transform the

recovery assumption will illustrate how Duffie and Singleton (1999) have met the second challenge. To obtain a binomial version of Jarrow and Turnbull (1995) we suggest the following binomial stochastic process for the pure rate of interest and the hazard rate.

$$r(t,i) = u_{rt} e^{\left(z_{\sigma t} (2i-t) \sqrt{\Delta T} \right)} \quad (3)$$

$$h(t,j) = h(t,i) = h(0,0) e^{\left(v_t \Delta T + \tilde{n}_{h,r} \frac{\sigma_{ht}}{\sigma_{rt}} r(t,i) \Delta T \right)} \quad (4)$$

The first binomial stochastic process is Black Derman and Toy (1990), where $r(t,i)$ refers to the pure interest rate that evolves in state i and time t , u_{rt} and $z_{\sigma t}$ are time dependent parameters that calibrates the interest rate tree by forward induction through use of state prices to the exogenously supplied Treasury zero yield and volatility curves respectively and ΔT is the time step. Note that when $t = 0$, then $r(t,i)$ is defined to be today's known short term pure rate of interest $r(0,0)$.

The second binomial stochastic process describes the evolution of the one period hazard rate and the joint probability distribution between $r(t,i)$ and $h(t,j)$. Through covariance between the pure rate of interest and the hazard rate, correlation $\rho_{h,r}$ between these parameters is included. This covariance is scaled by the time dependent pure interest rate volatility σ_{rt} leading to a multiplicative term that models the volatility of hazard rates as the responsiveness of hazard rates to the current pure rate of interest.⁴ Of course this means (4) generates a recombining hazard rate process since (3) is a recombining process. In (4) the time dependent parameter v_t calibrates the hazard rate tree by forward induction through use of corporate state prices to the corporate zero yield curve and σ_{ht} is the hazard rate volatility parameter. Note that when $t = 0$, then $h(t,j)$ is defined to be today's one period hazard rate (pseudoprobability of default) $h(0,0)$.

Together the binomial processes (3) and (4) form a model similar to Das and Tuffano (1996) in that we assume a linear scaling of cash flows. By applying the law of iterated expectations, the two binomial trees (3) and (4) are combined to calculate defaultable state prices which forms a single binomial tree. Procedurally we first calibrate the pure interest rate process at today's date $t=0$ to the Treasury zero yield and the Treasury volatility curves by adjusting the calibration factors u_{it} and $z_{\sigma t}$ respectively for all future dates. This obtains the pure interest binomial tree the values of which $[r(t, i)]$ are included in the hazard rate process (4)⁵. We then calibrate the hazard rate process, which is correlated with the Treasury interest rate process generated by the first calibration, to a credit risky zero yield curve by adjusting the calibration factor v_t . Simultaneously this calibration adjusts the structure of defaultable state security prices until the yield implied by the portfolio of all defaultable state securities that matures at a given date agrees with the corresponding yield from our estimate of the credit risky zero yield curve. This process continues for all future dates such that at each date, the yield of the replicating portfolio of defaultable state securities agrees with the corresponding yield from our estimate of the credit risky term structure.

Substituting (3) and (4) into (2) and rewriting slightly to highlight the RT assumption we obtain a binomial version of Jarrow and Turnbull (1995)⁶. The result is as follows.

$$V_0 = e^{-r(0,0)} 0.5[e^{-r(1,0)} + e^{-r(1,1)}] \times \{ [1 - 0.5(h(1,0) + h(1,1))] \times [1 - h(0,0)] V_2 + \phi_2 \} \quad (5)$$

where

$$\phi_2 = h(0,0) \delta [0.5(e^{r(1,0)} + e^{r(1,1)})] + 0.5[h(1,0) + h(1,1)] \delta (1 - h(0,0)) \quad (5a)$$

Equation (5) is a binomial version of Jarrow and Turnbull (1995). However unlike the original Jarrow and Turnbull (1995) this model allows for correlation so there are as many hazard rate states as there are pure interest rate states. Equation (5a) highlights the RT recovery assumption where conditional upon no prior default in any prior time and Treasury interest rate state; a recovery amount δ is paid at the end of the current period. Should default occur prior to maturity, the recovery amount is reinvested in a Treasury security until promised maturity. These recovery amounts are then included in (5). These recovery amounts are then multiplied by Treasury zero prices so these recovery amounts are ultimately expressed as a fraction of the value of a Treasury zero. This is the RT assumption that underlies Jarrow and Turnbull (1995) for the recovery amount that is paid at the end of the first period is a fraction of a one period Treasury zero. Similarly the recovery amount paid at the end of the second period is expressed as a fraction of a two period Treasury zero.

By restricting parameters to particular forms we can obtain other models. If correlation is zero then (5) becomes the classical Jarrow and Turnbull (1995). Specifically, (5) is transformed to

$$V_0 = e^{-r(0,0)} 0.5[e^{-r(1,0)} + e^{-r(1,1)}] \times \{[1 - h_1][1 - h_0]V_2 + \phi_2\} \quad (6)$$

Where

$$\phi_2 = h_0\delta[0.5(e^{r(1,0)} + e^{r(1,1)})] + h_1\delta(1 - h_0) \quad (6a)$$

Note that the RT assumption remains intact. Equation (6) is easier to implement than (5). We calculate just one h_t for each time period. Since h_t is equally likely at each interest rate state $r(t,i)$, we add the sum of expected values under h_t at time t and then present value this sum at each possible interest rate $r(t,i)$ at time t . We continue to do this rolling backwards through the corporate price tree.⁷ In contrast, to implement (5) we need to

calculate two binomial trees, one for $r(t,i)$ and another for $h(t,j)$, and then combine them to form $h(t,i)$. We then present value each expected value under $h(t,i)$ by the corresponding state contingent pure interest rate $r(t,i)$ at date t . We continue to do this rolling backwards through the corporate price tree.

If we adjust (5a) to conform to the return of market recovery assumption we obtain Duffie and Singleton (1999). Specifically, the Duffie and Singleton (1999) binomial version of (5) becomes

$$V_0 = e^{-r(0,0)} 0.5 [e^{-r(1,0)} + e^{-r(1,1)}] \times \{1 - (h(0,0) + 0.5[h(1,0) + h(1,1)])L_{t+1}\} V_{t+1} \quad (7)$$

This expression says that in the event of default $h(t,i)$ losses L_{t+1} are experienced at the end of the period. One minus this expected loss rate is then multiplied by the promised value V_{t+1} to find the expected value. Then we find the present value of this expected value. In (7), L_{t+1} is the end of period loss rate that is equal to the following expression under the RM recovery assumption.

$$L_{t+1} = 1 - \{1 - (h(0,0) + 0.5[h(1,0) + h(1,1)])\} \omega V_{t+1} \quad (7a)$$

In other words, (7a) says that upon default the investor loses an amount L . This amount is one minus the recovery amount. In turn this recovery amount is a fraction ω of the end of period survival contingent value of a \$1 face value zero.⁸ In contrast, the RT assumption in (5a) models recoveries as a fraction of a Treasury zero. The advantage of the RM formulation is that if recoveries are fractions of survival contingent values then values associated with prior period defaults are included in (7) as a *multiplicative* term. This facilitates forward induction, allowing us to apply pure interest rate modeling techniques directly to a corporate rate of interest without the extra computational complexity of adding values associated with prior period defaults to each corporate state price. In

contrast, (5a) and (6a) show that to implement the RT recovery method, one needs to make a separate *additive* calculation of expected conditional payoffs in (5) and (6) respectively in the event of default for all possible prior periods at each pure interest rate state.

II Empirical Procedures

The first step is to choose our sample. We collect forty-five default swap trades. For each trade we obtain the default swap ticket. This document contains important details of the premium, credit event parameters and the payout structure in the event of default of the bond insured by the credit default swap (hereafter, the reference security). The premium is specified as the total number of basis points to be paid each year. Payments are made in installments, typically quarterly, and are based on the specified notional principal amount. Applicable credit events are specified, which include “failure to pay”, “bankruptcy”, “repudiation” and “restructuring”.⁹ Payoffs in the event of default are defined as par value less the value of the defaulted security, where the value of the defaulted bond is established as the average of (typically) five independent dealer quotes. From this document we are able to identify the reference security and the precise date of trade.

To avoid extra complications we eliminate all credit default swaps whose reference security is a floating rate or a foreign currency bond. Therefore our sample contains thirty-one straight sovereign US dollar credit default swaps for the September 1997 to February 1999 time period. This time period contains the worst of the recent Asian currency crises so credit default swap premiums reflect these events. To obtain information about the effect these events had on the credit default swap market, we subdivide our sample into two categories, “Asian swaps” which evidently experienced a currency crisis and “non-Asian swaps” which evidently did not experience a currency crisis. This geographical classification is particularly easy to perform since all swaps in our remaining sample are sovereign swaps. We then plot the yield of the reference bond, the corresponding maturity Treasury yield, the resulting credit spread and the credit swap

premium. In general the reference security will be different at points along the time series plot, but since all are long-term dollar securities the resulting plot is reasonably continuous.

[Figures 1 and 2 about here]

Figures 1 and 2 show the time series plot of the non-Asian and Asian sub-samples. Figure 1 shows that for credit default swaps *not* experiencing a currency crisis the swap premium plots within the credit spread. However Figure 2 tells another story. Beginning in June 1998 credit swap premiums rise dramatically, now plotting above the credit spread. Later the credit premiums rise even further, now plotting above the Treasury yield.¹⁰

This data should provide a rigorous challenge for Duffie and Singleton (1999) and Jarrow and Turnbull (1995), as they are required to measure the market prices of credit default swaps subject to widely varying credit risk conditions. To implement these models we need estimates of the Treasury yield curve, the credit risky yield curve applicable to the reference bond and the correlation between the Treasury interest rates and the credit risky interest rates applicable to the reference bond. In addition we need Treasury interest rate volatility, and the volatility of credit risk. Finally we need the price of the reference bond, the binomial structure of hazard rates and the recovery rate of the reference bond in the event of default. Note that all of this information must apply on the date of the credit default swap trade.

We estimate the zero coupon Treasury yield curve on the date of each credit default swap transaction by applying the Nelson and Siegle (1987) yield curve estimation procedure to Treasury transaction prices supplied by the National Association of Insurance Companies' (NAIC) database. The NAIC database contains the details of each bond transaction member insurance companies report to the national body, representing 30 to 40% of all US domestic over the counter bond trading activity. Each transaction contains all the important details such as the CUSIP of the bond, transaction date, clean price,

accrued interest and day count conventions. A separate cross sectional file contains all the major bond covenants of each issue. This information can be linked up with the transaction file, so we are able to avoid using transactions tainted by optionality. We estimate a ten-year Treasury yield curve as the maturity of the reference bond in all our default swaps is never longer than ten years.

Unfortunately we find that the liquidity of the Treasury market dried up during 1999 so we were unable to find a sufficient number of Treasury transactions at the required breadth of maturities to estimate a ten-year Treasury yield curve for the three dates we need in 1999. We obtain the 1999 Treasury yield curves in the following way. First we obtain the par coupon Treasury yield curve on the days that the credit default swaps traded from datastream's 401N program. We then applied Nelson and Siegle (1987) to extract the zero coupon yield curve from this information.

We also obtain the price and yield of the reference bond and the 1, 2, 3, 4, 5, 7 and 10 year at the money implied interest rate cap volatility from Datastream's 901b program at the same dates that the credit default swaps were sold. We linearly interpolate implied cap volatility to form an estimate of the Treasury volatility curve. We estimate the applicable credit risky yield curve by calibration in the following way.

We first calibrate the Black Derman and Toy (1990) pure interest rate process to the Treasury zero coupon and cap volatility curves on the trade date of the credit default swap. We initially assume that the credit risky yield curve is the sovereign yield curve plus a credit spread calculated as the difference between the reference bond's yield and the corresponding maturity US Treasury yield. Then we calibrate the candidate model to this credit spread using reasonable values for the recovery fraction, credit risk volatility and correlation between hazard rates and Treasury interest rates. Later we test our initial estimates of key parameters to ensure that these choices do not materially affect our results.

We chose recovery rates that are consistent with the credit rating of the reference bond. This information is available from Altman, Cooke and Kishore (1999) who report the average trade price of defaulted bonds one month after default. These averages are computed over the 1971 to 1998 time period, and are reported by broad rating category. We find the historical credit rating of the candidate reference bond from Standard and Poors web site. We chose credit risk volatility as one tenth of Treasury interest rate volatility since we suspect that credit risk volatility is related to, but less than Treasury interest rate volatility. Finally we assume that the correlation between Treasury interest rates and hazard rates applicable to the insured bond is -0.1 since Collin-Duffresne, Goldstein and Martin (2001) suggest that correlations between Treasury interest rates and the credit spread are negative.

Based on these estimates we run a given candidate model to see if these choices for the candidate credit risky yield curve, recovery fraction, credit risk volatility and correlation between Treasury and credit risky interest rates are able to replicate the known price of the reference bond. When running the model, the binomial structure of pure (credit risk free) interest rates and hazard probabilities are calibrated until they replicate the given Treasury and the initial estimate of the credit risky yield curve. The binomial structure of Treasury interest rates and hazard probabilities, along with the recovery fraction, also generates a binomial structure of credit risky interest rates. This binomial structure of credit risky interest rates is then used to price the reference bond.

Usually the price of the reference bond is not replicated. We discover that changes in the credit risk volatility and correlation between Treasury rates and hazard rates do not appreciably change the price of the reference bond that we obtain by the two credit risk models. For example, by changing credit risk volatility by a factor of ten results in less than \$0.01 change in the price of the reference bond. Similarly the price of the bond obtained by both models is insensitive to large variations in correlation between Treasury rates and hazard rates. These results are not surprising as the underlying bond is a cash instrument that should be much less sensitive to volatility and correlation than a derivative security.

Furthermore we find that the price of the underlying bond is not sensitive to changes in the recovery rate. This is what we should expect because as the recovery rate increases (decreases), a renewed calibration of the candidate credit risk model will have larger (smaller) hazard probabilities. In other words, the calibration process takes the credit spread as given so for a given credit risk model an increase in the recovery rate is offset by an increase in the hazard rate. Therefore the renewed calibration replicates the credit spread with a different combination of hazard and recovery rates that results in the same price of the reference bond.

However, the reference bond's price obtained by the two candidate models is sensitive to the size of the credit spread. Therefore we generate a new credit risky yield curve by adjusting the credit spread until we replicate the market price of the reference bond. In this way we estimate the applicable credit risky yield curve by calibration that as explained earlier is consistent with value additivity. We find that the Duffie and Singleton (1999) and Jarrow and Turnbull (1995) models agree as to the size of the spread, the difference is always less than two basis points, even for below investment grade bonds.

III Empirical Estimates

Now using the calibrated pure interest volatility, credit spread and hazard rates, and initial estimates of the recovery rate, credit correlation and credit volatility, we find the default value, the present value of payments from the credit default swap in the event of default, according to equation (8) below.

$$\text{Default Value} = E_0 \left(\sum_{t=0}^n \sum_{i=0}^n h(t,i) [100 - B(t,i) \ddot{a}] e^{-\{ r(t,i) \}} \right) \quad (8)$$

Note that where $i > t$, $h(t,i)$ and $r(t,i)$ are zero. Equation (8) says that the default value of the swap is the present value of expected payoffs in the event of default. The payment is

determined by the swap contract. In our sample the payment in the event of default is defined as face value less the value of the defaulted reference bond $B(t,i)\delta$ where δ is the recovery rate. The entire expression is calculated under the risk neutral expectation operator E_0 since interest rates are stochastic and correlated with factors that influence default. The two candidate models differ in how they determine the hazard rates and the values received in the event of default. Specifically Duffie and Singleton (1999) model recovery amounts as a fraction of the survival contingent value of the reference security (RM) whereas Jarrow and Turnbull (1995) model recovery amounts as a fraction of a Treasury zero (RT). As noted earlier, since both models are calibrated to the same exogenous credit spread, different recovery amounts result in different estimates of the hazard probabilities.

Next we convert the basis point price of the credit default swap to premium values in (9) below.

$$\text{Premium Value} = E_0 \left(\sum_{t=0}^n \sum_{i=0}^n [1 - h(t,i)] \bullet S_t \bullet M \bullet e^{-\{r(t,i)\}} \right) \quad (9)$$

Note that where $i > t$, $h(t,i)$ and $r(t,i)$ are zero. The buyer pays the premium value calculated as the swap rate S_t as quoted in basis points times the notional amount of the reference bond M that we set to be 100. Payments are conditional upon no prior default $(1-h(t,i))$ at any time t and state i . The present value of this stream of conditional payments is found by solving backwards using the binomial structure of pure rates of interest. Like (8) the entire expression is calculated under the risk neutral expectation operator E_0 since interest rates are stochastic and correlated with factors that influence default. As explained above, Duffie and Singleton (1999) and Jarrow and Turnbull (1995) obtain different hazard rates as they assume different recovery amounts.

Subtracting (9) from (8) will find the economic value of the credit default swap from the buyer's perspective. It is tempting to suggest that a credit default swap should have an economic value of zero, that is $(8) = (9)$, when markets are complete and frictionless. In

fact, Duffie (1999) finds that this is the case for credit default swaps that insure floating rate reference bonds. However, we think there is an additional condition when dealing, as we do here, with fixed coupon bonds. Specifically, the correlation between pure rates of interest and the hazard rate must be zero.¹¹

The degree of correlation between the pure rate of interest and the hazard rate is critical because it affects the cost of hedging a credit default swap. Consider a hedge portfolio consisting of a long position in a Treasury bond B_f and a short position in the reference bond B_c that is subject to credit risk. For simplicity, let both bonds be priced at par and be of the same maturity. This position is (nearly) equivalent to a selling a credit default swap S that insures the reference bond in the event of default. In other words,

$$S \cong B_f - B_c \quad (10)$$

If the reference bond does not default, then the credit default swap expires worthless and B_f and B_c mature at par, so (10) holds. However, if the reference bond defaults, losses on the reference bond are recovered from the credit default swap, so the default payoff on B_c is still par. B_f however, may be worth more or less than par value at the date of default, depending upon what has happened to pure rates of interest, so the cost of hedging the swap may cost more (or less) than (10).

If the correlation between pure rates of interest and hazard rates were zero, then the relationship between interest rates and default is unsystematic. With large enough portfolios, over time losses on the above hedge portfolio will be offset by gains. Therefore (10) is a strict equality as the difference between the long Treasury bond B_f and the short corporate bond B_c equals the cost of hedging the credit default swap S . This also means that the credit default swap premium would equal expected payoffs since from (10) the price of the credit default swap equals the expected payoff in the event of default. In other words the credit default swap has an economic value of zero since payoffs on the swap (8) equals the swap premium (9).

If the correlation between pure rates of interest and hazard rates are positive, this means that on average the above hedge portfolio will actually experience a loss since default will tend to occur in states where interest rates are high and the value of the hedging Treasury bond is below par. This means the cost of hedging is greater than that suggested by (10) and the credit default swap has a negative economic value, as payoffs (8) are less than the swap premium (9). If the correlation between pure rates of interest and hazard rates are negative, this means that on average the above hedge portfolio will actually experience a gain since default will tend to occur in states where interest rates are low and the value of the hedging Treasury bond is above par. This means the cost of hedging is less than that suggested by (10) and the credit default swap has a positive economic value, as payoffs (8) are more than the swap premium (9).

Longstaff and Schwartz (1995), Duffee (1998), Collin-Duffresne, Goldstein and Martin (2001) and Papageorgiou and Skinner (2001) all find that Treasury interest rates are negatively related to the credit spread, suggesting that pure rates of interest are negatively related to hazard rates. This suggests that we should expect positive economic values for credit default swaps, even in complete, frictionless markets.

The above analysis assumes complete, frictionless markets. Now consider the likely impact of liquidity. Given exogenous estimates of recovery rates, then the structure of hazard rates will be determined by the credit spread. We think that the credit spread will be “too wide” relative to what they should be in a frictionless market because US Treasury bonds are more marketable than the corresponding maturity but more credit risky reference bond. Consequently hazard rates would be overestimated because the candidate credit risk model will be calibrated to a credit spread that reflects differences in liquidity as well as credit risk. This would underestimate the value of payments to the seller of the swap in (9) and overestimate the value of the credit default swap payoff to the buyer in (8). This suggests that the Duffie and Singleton (1999) and Jarrow and Turnbull (1995) models would typically measure positive economic values for credit default swaps.

Therefore it is an interesting exercise to see whether the candidate models do in fact find zero or positive economic values for market traded credit default swaps. We find the values of the thirty-one credit default swaps using the calibrated Treasury and corporate yield curves and the pure interest rate volatility curve. We use an estimate of correlation between Treasury interest rates and hazard rates of -0.1 and hazard volatility of one tenth of pure interest rate volatility. As discussed earlier we use the Altman, Cooke and Kishore (1999) average recovery rates as estimates of the recovery fraction in the event of default that is consistent with the credit rating of the reference security. Since the RM assumption that underlies the Duffie and Singleton (1999) model cannot separately identify the recovery rate as a single value (it is survival contingent), we replace ω with the recovery rate δ in (7a) when running the model. As the implied cash value of a fraction of a survival contingent zero (RM) is less than the corresponding fraction of a Treasury zero (RT), the value of the RM recovery rate should be higher in order for it to be comparable to the RT recovery rate. The result of this exercise is reported in Tables 1, 2 and 3 below.

[Tables 1 and 2 about here]

Table 1 shows that for credit default swaps that evidently did not experience problems with the Asian currency crisis, Duffie and Singleton (1999) estimates positive economic values from the point of view of those buying credit protection. Table 2 shows that for Jarrow and Turnbull (1995) most have positive economic values but ten of twenty-three credit default swaps have negative economic values. However Table 3 shows that for those credit default swaps that evidently did experience problems with the Asian currency crisis, both models agree that all credit default swaps have a negative economic value.¹²

[Table 3 about here]

Notice that Duffie and Singleton (1999) consistently reports higher premium prices and default values than Jarrow and Turnbull (1995). This happens because any given recovery fraction used for both models implies lower recovery amounts and lower hazard

rates in Duffie and Singleton (1999). This result is consistent with the analysis of Delianedis and Lagnado (2002) who agree that the RT assumption typically implies higher hazard rates than that implied by the RM assumption. These lower hazard probabilities but higher default payoffs in Duffie and Singleton (1999) lead to higher default values (8). Similarly the premium value (9) is higher for Duffie and Singleton (1999) since by calibration a lower recovery amount implies a lower hazard rate. This leads to higher probabilities of premium payments and so to higher premium values in (9).

To assure ourselves that these results are not materially affected by our choices for the correlation between pure and credit risky interest rates, and for credit risk volatility, we recomputed these results for a wide range of possible values for these parameters. We find that the premium value (9) and the default value (8) increase very slightly, less than one half of a cent, as the hazard rate volatility increases by a factor of ten. Similarly, as hazard and Treasury rate correlation varies from -0.1 to ± 0.5 , the default value changes only very slightly.

Schönbucher (1999) finds the same results when pricing hypothetical credit default swaps. The credit default swap pays off only in the event of default, an unlikely event even for bonds rated below investment grade. However the payoff in the event of default is relatively large, so the credit default swap has a modest value. The correlation between credit risk free and credit risky interest rates and hazard rate volatility has little influence in determining the default value of the credit default swap since they can only have an impact in the event of default which has a small probability mass. The premium value of the credit default swap (9) is similarly insensitive to these two parameters as in essence the premium value is a cash security like the reference bond. As we have seen, the reference bond is sensitive to the credit spread, and insensitive to the correlation between Treasury rates and hazard rates and the hazard volatility.

Since we expect to observe positive economic values due to a liquidity bias, then we suggest that the consistently negative economic values found in Table 3 are likely due to a moral hazard problem. The explanation is as follows.

All swaps in our sample include restructuring as a credit event that triggers payments from the default swap. Since the buyer of the credit default swap is often the investor in the reference bond insured by the credit default swap, then in essence the insured party may also influence payments on the insurance contract. Therefore we have a moral hazard problem. For example, if the reference bond were likely to default, then the owner of the reference bond may press for an early restructuring, prior to the necessity to do so because of actual default. An early restructuring is desirable from their perspective since delays in restructuring may result in more severe defaults later as the issuer may delay in facing up to their problems. The owner of the reference bond could tempt the issuer to restructure early by saying offering to accept a replacement security with a lower coupon in place of the high coupon reference security. Since the owner of the reference bond is insured by the credit default swap, losses incurred by the restructuring are offset by payments on the credit default swap. Overall at least one, possibly both the issuer and owner of the reference security gain but neither would suffer losses. Instead, the seller of credit protection incurs losses by paying the difference between the value of the reference bond and the replacement bond.

The seller of credit protection now faces an asymmetric information problem. Some buyers of credit protection may know more about the possibility of restructuring than the seller of credit protection. These knowledgeable buyers of credit protection would buy credit default swaps that include restructuring as a credit event if the swap premium under prices the likelihood of restructuring. Therefore the seller of credit protection is encouraged to require higher credit default swap prices.

All candidate credit default swap models may be incapable of picking up this larger premium, as it would be included in the premium value (9) but maybe not in the default value (8). The latter is a possibility since some, but not necessarily all the investors in the

reference bond own the credit default swap written on this bond. Furthermore some investors will not even know that other investors have bought credit protection since credit default swaps trade over the counter. Therefore the likelihood of restructuring due to the moral hazard problem may not be included in the price of the reference bond and consequently may not be included in the credit spread. Since all candidate credit risk models are fine-tuned to agree with the credit spread the credit risk model may not include the impact of the moral hazard problem and so (8) may underestimate the likelihood of restructuring. This would lead to negative economic values since (9) includes the extra swap premium in S , but (8) and (9) may underestimate the hazard probability.

In the absence of the Asian currency crisis, we generally observe the anticipated positive economic values for credit default swaps. However where the possibility of restructuring is more likely, namely for the below investment grade reference bonds subject to the Asian currency crisis, we consistently observe negative rather than positive economic values for the corresponding credit default swaps. This means that compensation for bearing credit risk as measured in (9) is more than the anticipated cost of credit risk as measured in (8) even though the hazard rate is probably overestimated due to a liquidity bias. We suggest that this occurred because the moral hazard problem was so severe in the case of reference bonds subject to the Asian currency crisis that sellers of credit protection demanded (and received) a visible “restructuring risk premium” due to the moral hazard problem.

IV Summary and Conclusions

We examine the empirical performance of the Duffie and Singleton (1999) and Jarrow and Turnbull (1995) models on a sample of thirty-one credit default swaps that traded during 1997 to 1999. We find that, consistent with the theoretical predictions of Delianedis and Lagnado (2002), the RM assumption that underlies Duffie and Singleton (1999) returns higher premium and default values for credit default swaps than the RT assumption that underlies Jarrow and Turnbull (1995). We are able to estimate these

models, as we are able to generate a credit risky yield curve that is applicable to the underlying reference bond. We are able to estimate this yield curve by calibration by appealing to basic financial theory.

We generally find positive economic values (from the buyers perspective) for non-Asian credit default swaps, which is what we expect given that credit spreads reflect liquidity as well as credit risk. However, both models consistently find negative economic values for Asian credit default swaps. We suggest this happens because of a moral hazard problem. Sellers of Asian credit default swaps suspected that some buyers were also investors in the reference bond. Sellers then believed that some buyers could control the conditions of payoff from the credit default swap. Faced with information asymmetry, being unable to distinguish between those buyers that have accurate information concerning the likelihood of restructuring and those that do not, the sellers of credit protection demanded, and evidently received, a visible “restructuring premium”.

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Table 1
Non-Asian Swaps-Duffie and Singleton (1999)

This table reports the economic values for non-Asian swaps that traded from March 31, 1998 until February 22, 1999. These values are found using the historical recovery rate of 60% for A rated, 50% for BBB rated and 37% for B rated bonds.

<i>Date</i>	<i>Bond Life Swap</i> <i>(in months)</i>	<i>Swap Life (in months)</i>	<i>Default Value (in \$ per 100)</i>	<i>Premium Value (in \$ per 100)</i>	<i>Difference (in \$ per 100)</i>	<i>Credit Spread (in basis points)</i>	<i>Rating</i>
31/03/98	119	108	6.89	4.47	2.42	99	BBB
06/05/98	117	60	4.38	2.16	2.22	104	BBB
28/05/98	117	108	7.17	4.11	3.06	88	BBB
03/06/98	116	57	3.77	2.00	1.77	94	BBB
16/06/98	47	47	2.57	2.33	0.24	76	A
30/07/98	115	115	6.98	2.81	4.17	97	BBB
06/08/98	78	60	21.87	18.26	3.61	504	B
21/08/98	114	60	3.84	2.28	1.56	92	BBB
01/09/98	114	114	11.51	5.28	6.24	156	BBB
02/09/98	114	60	5.98	3.31	2.66	140	BBB
02/09/98	114	114	10.36	5.66	4.70	140	BBB
07/09/98	113	60	5.12	3.08	2.04	122	BBB
08/09/98	113	60	5.38	3.00	2.38	131	BBB
15/09/98	113	60	5.66	3.46	2.21	136	BBB
24/09/98	113	113	9.23	7.12	2.11	126	BBB
11/11/98	111	84	6.89	4.75	2.14	122	BBB
17/11/98	111	60	4.74	3.05	1.70	114	BBB
20/11/98	111	60	4.36	2.93	1.43	103	BBB
24/11/98	111	111	8.15	5.00	3.15	115	BBB
16/12/98	110	84	6.44	3.47	2.97	115	BBB
04/02/99	108	108	5.18	3.10	2.08	75	BBB
22/02/99	108	108	8.91	3.05	5.85	76	BBB
23/02/99	108	60	2.97	1.63	1.34	71	BBB

Table 2
Non-Asian Swaps-Jarrow and Turnbull (1995)

This table reports the economic values for non-Asian swaps that traded from March 31, 1998 until February 22, 1999. These values are found using the historical recovery rate of 60% for A rated, 50% for BBB rated and 37% for B rated bonds.

<i>Date</i>	<i>Bond Life (in months)</i>	<i>Swap Life (in months)</i>	<i>Default Value (in \$ per 100)</i>	<i>Premium Value (in \$ per 100)</i>	<i>Difference (in \$ per 100)</i>	<i>Credit Spread (in basis points)</i>	<i>Rating</i>
31/03/98	119	108	3.86	4.27	-0.41	100	BBB
06/05/98	117	60	2.27	2.09	0.18	106	BBB
28/05/98	117	108	3.99	3.93	0.06	90	BBB
03/06/98	116	57	2.51	1.95	0.57	95	BBB
16/06/98	47	47	Fail	Fail	Fail	77	A
30/07/98	115	115	3.90	2.68	1.22	98	BBB
06/08/98	78	60	15.77	16.00	-0.23	505	B
21/08/98	114	60	2.19	2.22	-0.03	93	BBB
01/09/98	114	114	6.56	4.90	1.66	157	BBB
02/09/98	114	60	3.42	3.19	0.24	141	BBB
02/09/98	114	114	5.86	5.29	0.57	141	BBB
07/09/98	113	60	2.92	2.97	-0.05	123	BBB
08/09/98	113	60	3.12	2.89	0.23	132	BBB
15/09/98	113	60	3.24	3.33	-0.09	137	BBB
24/09/98	113	113	5.19	6.71	-1.52	127	BBB
11/11/98	111	84	3.88	4.54	-0.65	123	BBB
17/11/98	111	60	2.70	2.95	-0.25	115	BBB
20/11/98	111	60	2.43	2.85	-0.42	104	BBB
24/11/98	111	111	4.57	4.74	-0.17	116	BBB
16/12/98	110	84	3.62	3.32	0.30	116	BBB
04/02/99	108	108	4.32	2.99	1.33	76	BBB
22/02/99	108	108	4.96	2.90	2.05	77	BBB
23/02/99	108	60	1.68	1.59	0.09	72	BBB

Table 3
Asian Swaps

This table reports the economic values for Asian swaps that traded from Sept 8, 1997 until July 17, 1998. These values are found using a 60% and 39% recovery rate for AA and BB rated reference bonds respectively. In the first column, DS = Duffie and Singleton (1999) and JT = Jarrow and Turnbull (1995).

<i>Swap</i>	<i>Date</i>	<i>Bond Life (in months)</i>	<i>Swap Life (in months)</i>	<i>Default Value (in \$ per 100)</i>	<i>Premium Value (in \$ per 100)</i>	<i>Difference (in \$ per 100)</i>	<i>Credit Spread (in basis points)</i>	<i>Rating</i>
DS	08/09/97	61	60	4.25	2.99	1.27	98	AA
JT	08/09/97	61	60	Fail	Fail	Fail	99	AA
DS	09/06/98	54	54	17.56	21.66	-4.09	432	BB
JT	09/06/98	54	54	12.06	19.52	-7.47	433	BB
DS	30/06/98	53	53	18.13	22.29	-4.16	453	BB
JT	30/06/98	53	53	12.69	20.00	-7.31	454	BB
DS	30/06/98	53	53	18.13	20.89	-2.76	453	BB
JT	30/06/98	53	53	12.69	18.80	-6.11	454	BB
DS	13/07/98	39	12	4.97	6.55	-1.58	532	BB
JT	13/07/98	39	12	4.09	6.30	-2.21	533	BB
DS	14/07/98	52	12	3.92	6.04	-2.13	415	BB
JT	14/07/98	52	12	3.21	5.82	-2.62	416	BB
DS	15/07/98	52	12	3.96	5.99	-2.03	419	BB
JT	15/07/98	52	12	3.24	5.81	-2.57	420	BB
DS	17/07/98	52	12	3.96	6.04	-2.08	419	BB
JT	17/07/98	52	12	3.24	5.85	-2.61	420	BB

Figure 1
Non Asian VS US Treasury

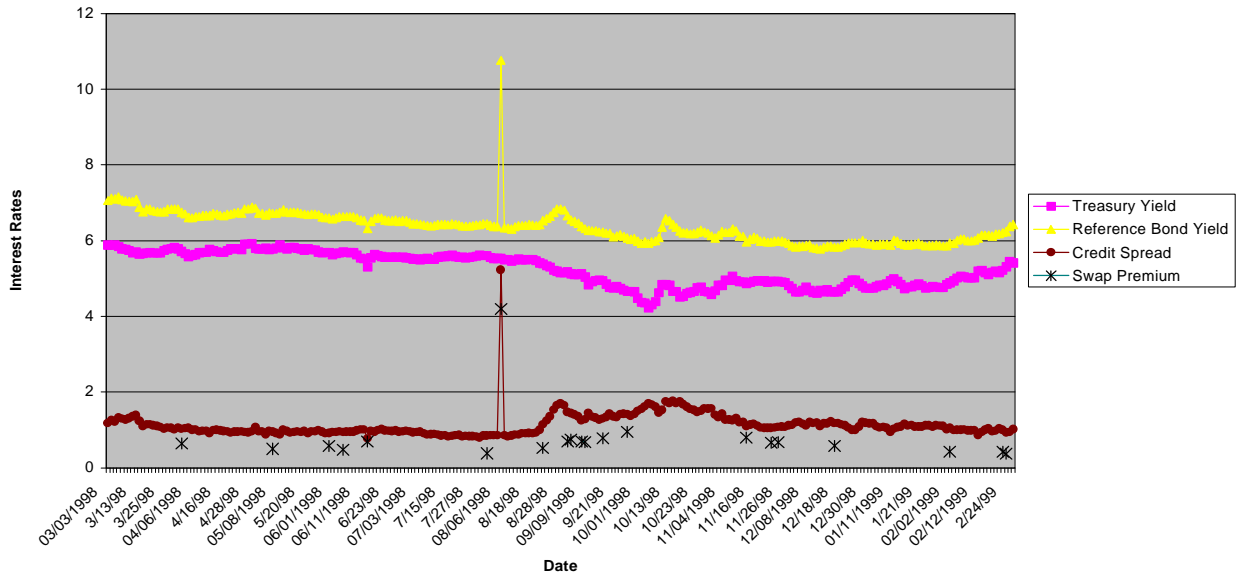
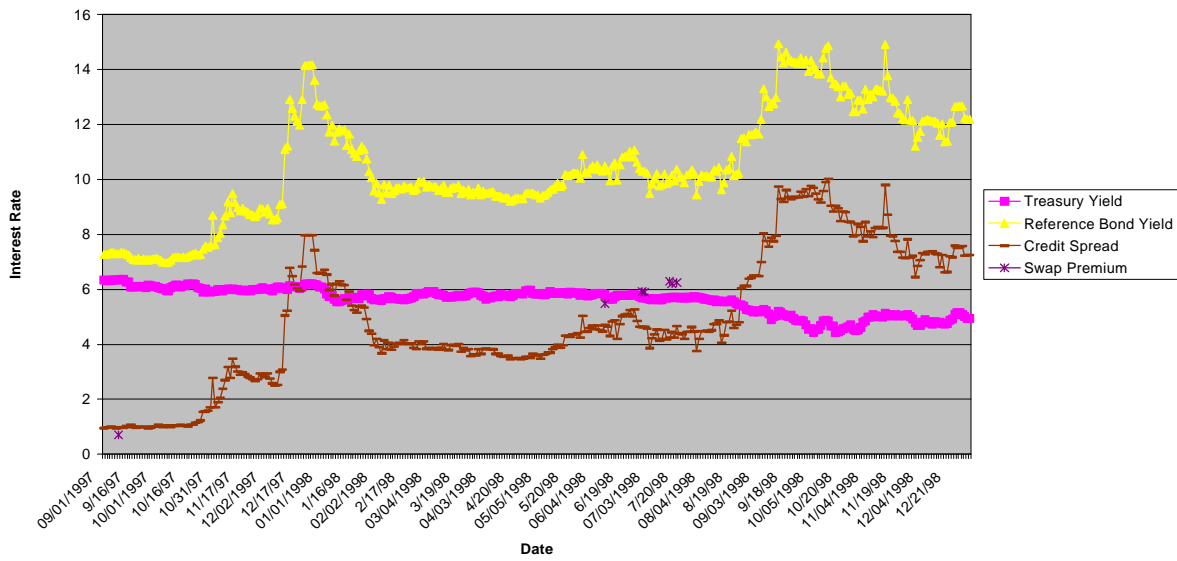


Figure 2
Asian VS Treasury



¹ For a discussion of the moral hazard problem from the practitioner's perspective, see Bennett (2000), *Risk*, Vol.14, no. 3 (March 2001), pages S6-S7, also Cass (2000), same issue S16-S18.

² Sometimes it is suggested that we use the balance sheet identity and value the firm's assets as the value of the equity and liabilities since equity and many liabilities trade. Unfortunately, a large portion of a firm's liabilities does not trade as well, so this approach is not a solution.

³ Harrison and Kreps (1979) show that equivalent martingale (risk neutral probability) measures exist in the absence of arbitrage. These measures are unique if markets are complete.

⁴ Scaling the covariance between two variables by the variance of the independent variable is very common in finance. Some examples are OLS hedge ratios and the CAPM model.

⁵ Details of how to implement Black Derman and Toy (1990) can be found in Clewlow and Strickland (1998), chapter 8.

⁶ Since we include correlation between credit risky and Treasury interest rates, (5) represents a minor extension to Jarrow and Turnbull (1995) who assume zero correlation between these two parameters.

⁷ Alternatively we can roll forwards through the corporate state price tree by multiplying expected values under hazard probabilities by pure interest state security prices. The same comment applies to binomial version of Duffie and Singleton (1999).

⁸ Duffie and Singleton (1999) also propose a "return of face value" (RF) recovery assumption. In this case the fractional loss L_t is simply a fraction of next periods promised amount or $(1-\alpha)V_{t+1}$. They demonstrate that there is little difference between the results obtained whether we use the RF or RM recovery assumption, a result that we also find here. Therefore for the sake of brevity we omit mention of this in the main text.

⁹ A bond may "fail to pay" and yet not cause bankruptcy because a bond may miss a coupon payment and pay later without any bankruptcy event. In the event of a missed coupon payment on the underlying bond, the credit default swap will payoff.

¹⁰ It is tempting to suggest that the credit default swap premium should not be larger than the credit spread since this would suggest that insuring the bond against default is more costly than compensation granted in the bond market for credit risk. This view is erroneous since it assumes that the maturity of the credit default swap is the same as the underlying bond. For Asian swaps, this is not case. In fact, most Asian swaps have a shorter maturity than the underlying reference bond so the high swap premiums may well mean that credit risk is extraordinarily high in the short term that is averaged in bond market yield quotes.

¹¹ This also assumes that the credit default swap contract is not vulnerable. Specifically, the writer and buyer of credit protection are not subject to credit risk. A weaker condition is that the writer and buyer are equally vulnerable.

¹² Figure 2 shows that the very first Asian credit default swap's premium was not extraordinarily high. Furthermore the credit rating reported in Table 2 is investment grade and the date of trade was September 8, 1997, prior to the Asian currency crisis. We conclude that the first Asian credit default swap was not subject to the Asian currency crisis. Also note that Jarrow and Turnbull (1995) failed to converge using historical AA recovery rates as the model did earlier in attempting to price the non-Asian swap of 16/06/98.

