An Overview of Credit Derivatives

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Credit risk

- The distribution of financial loss due to a **broken financial agreement**, for example
  - Agency downgrade
  - Chapter 11
  - Failure to pay according to schedule
- Pervades **virtually all** financial transactions
- A credit derivative is a security that facilitates the distribution of credit risk

Outline

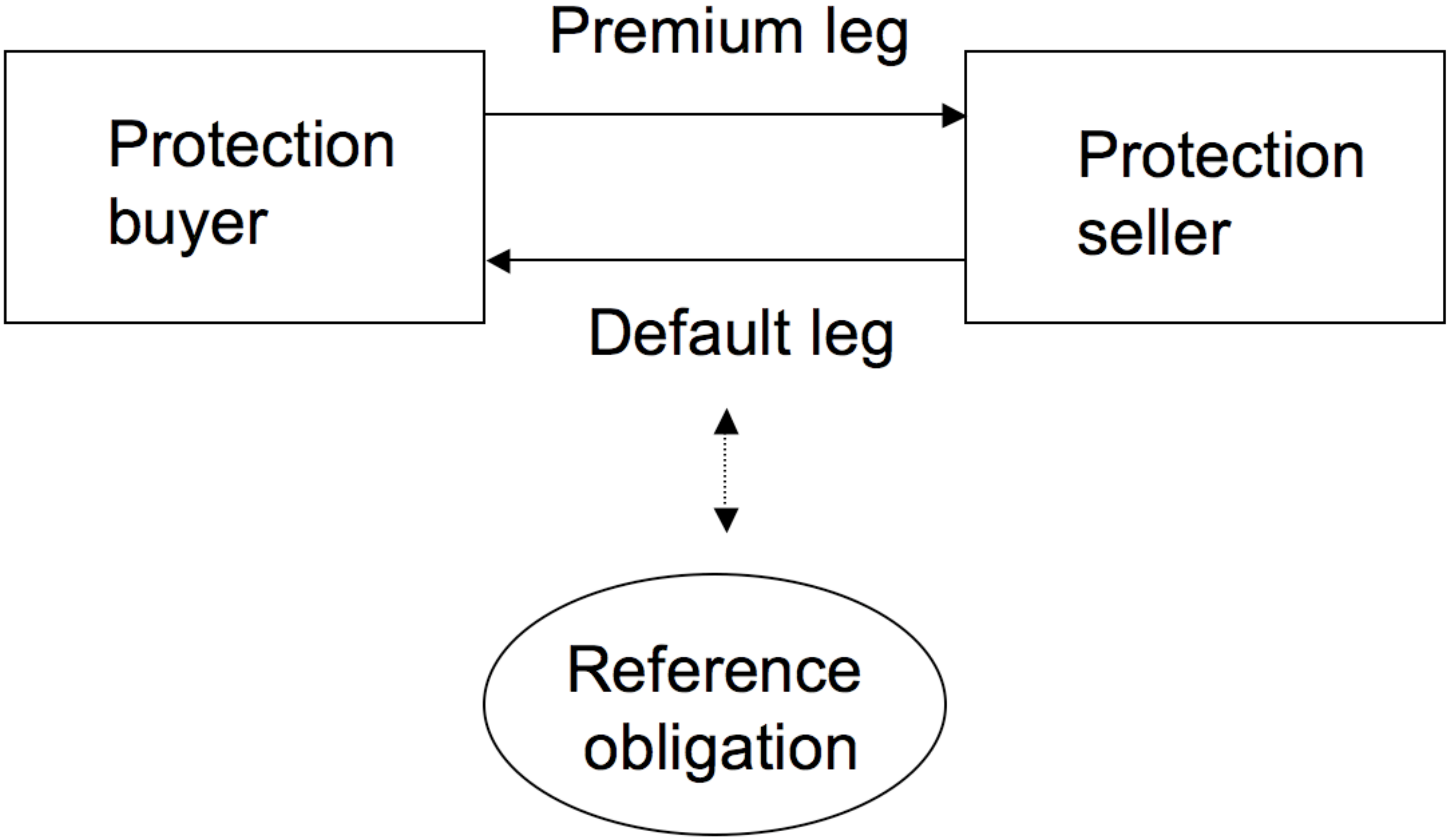
1. Motivating Example: Credit Default Swap (CDS)
2. Point processes
   - (a) Transform
   - (b) Simulation
3. Corporate Bonds and CDS
4. Index Swaps and Tranches

References

- We will closely follow my 2009 article "An Overview of Credit Derivatives," which is available on my website `www.stanford.edu/~giesecke` along with these slides
- We will provide detailed references

Credit default swap

Mechanics



Premium leg

Protection buyer

Protection seller

Default leg

Reference obligation

Credit default swap

Swap legs

- A CDS is a bilateral over-the-counter transaction
  - **Default leg**
    The protection seller compensates the protection buyer for the loss if the reference entity experiences a credit event before the maturity of the contract
  - **Premium leg**
    The protection buyer pays a quarterly fee, called the CDS spread and stated as a fraction of the notional per annum, until the credit event or maturity, whichever is first
- The fair spread equates the values of the two legs

Credit default swap

Transfer of credit risk

- Position of parties
  - The protection buyer is short credit without the risk of short squeezes or repo specials
  - The protection seller is long credit
- Similar to an insurance contract, with the difference that the protection buyer often has no relation to the reference entity
  - New regulation is underway regarding naked positions
- No upfront notional is exchanged–the transaction is unfunded and therefore off-balance sheet

Credit default swap

Applications

- Hedging
  - A bank may obtain regulatory capital relief by buying protection on a loan it has made
- Speculation
  - A fixed-income investor can assume credit exposure by selling protection without having to fund a cash bond purchase
  - An investor buying protection bets that the credit risk of the reference name increases
  - Off-balance sheet

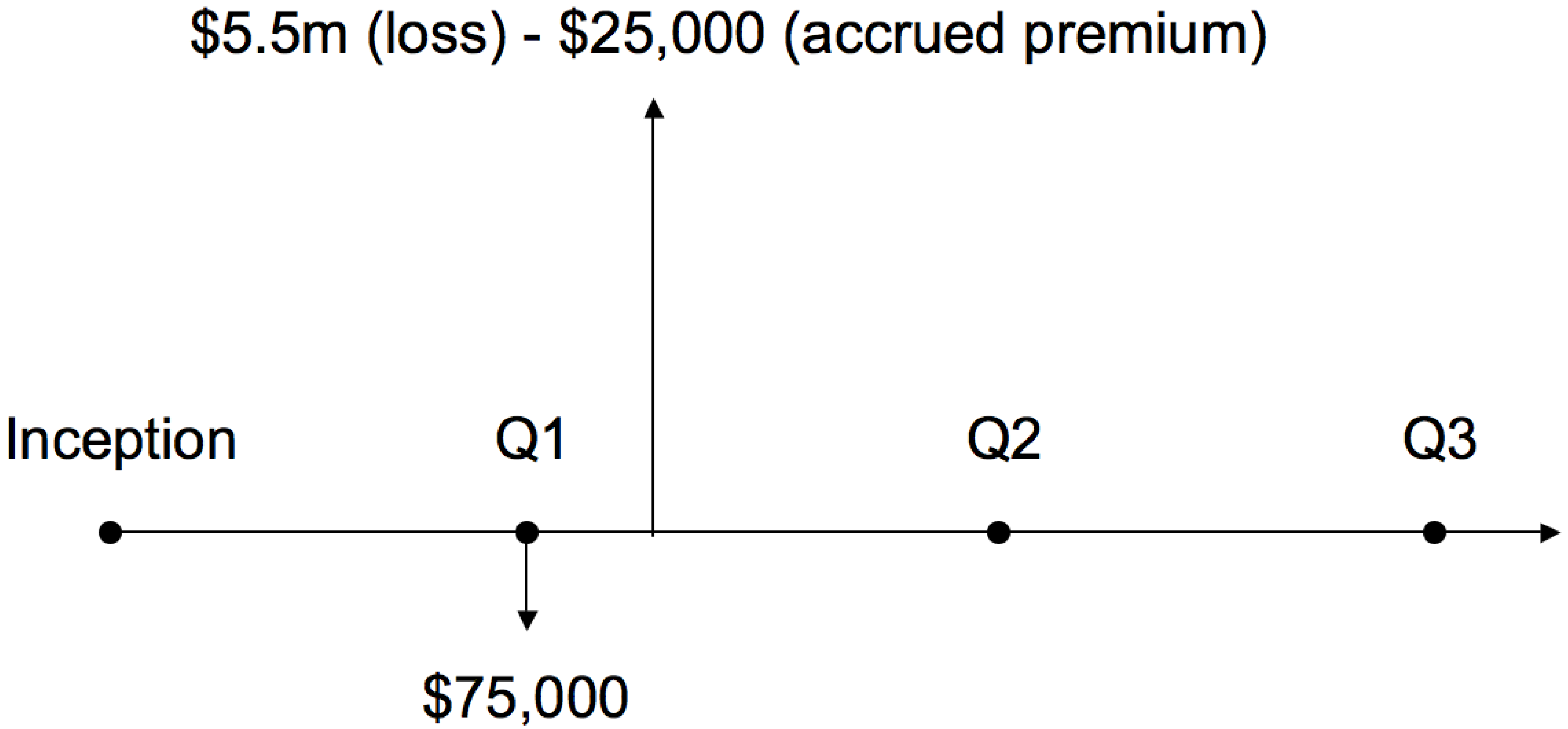
Credit default swap

Example

- A protection buyer purchases 5yr protection on a corporate name with notional $10m at an annual spread of 300bp
- After 3 months, the protection buyer makes the first payment, roughly equal to $\$10m \times 0.03 \times 0.25 = \$75,000$
- The reference name defaults 1 month after the first payment and the reference obligation has a recovery rate of 45%
    - The protection seller compensates the protection buyer for the loss by paying $\$10m \times (100\% - 45\%) = \$5.5m$ at default
    - The protection buyer pays the accrued premium, roughly equal to $\$10m \times 0.03 \times 1/12 = \$25,000$, at default
- The contract expires

Credit default swap

Cash flows to the protection buyer



Credit default swap

Reverse engineering

- Spreads for various maturities between 0.5 and 10 years are quoted for a growing universe of reference names
- From market spreads we can infer a name's risk-neutral probability of default over future horizons
  - Mark-to-market of credit swap positions
  - Construction of forward spread curve
  - Design of credit trading strategies
- Need a model for default timing and the loss at default

Point process

Basic setting

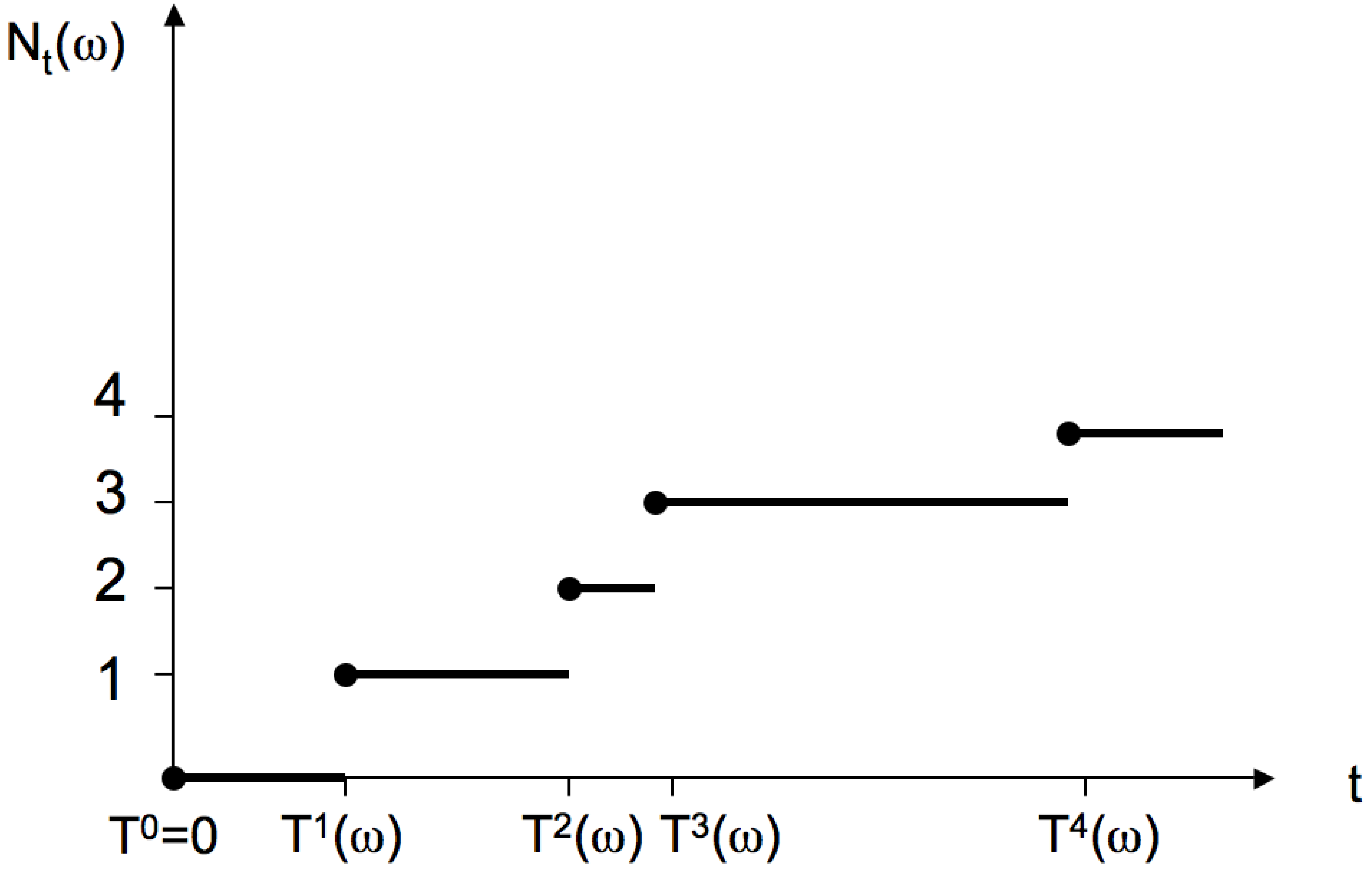
- Probability space $(\Omega, \mathcal{F}, \mathbb{P})$ with filtration $\mathbb{F} = (\mathcal{F}_t)_{t \geq 0}$
- Consider a sequence of default stopping times $(T^k)_{k \geq 0}$
  - $0 = T^0 < T^1 < T^2 < \dots$
  - $\lim_{k \to \infty} T^k = \infty$
- The stopping times generate the **default process** N by

$$N_t = \sum_{k \geq 1} 1_{\{T^k \leq t\}}$$

  - N is non-explosive: $N_t < \infty$ almost surely so an infinite number of defaults cannot accumulate at a finite time
  - N has the same information as (T^k)

Point process

The sample paths of N are right continuous with left limits



Point process

Compensator and intensity

- The default process N is a submartingale:

$$N_t = \mathbb{E}(N_t \,|\, \mathcal{F}_t) \leq \mathbb{E}(N_s \,|\, \mathcal{F}_t) \quad t \leq s$$

- The Doob-Meyer theorem guarantees that $N = A + M$ where A is a nondecreasing, right continuous predictable process called the **compensator** and M is a (local) martingale
- The **intensity** process $\lambda \geq 0$ generates A:

$$A_t = \int_0^t \lambda_s \, ds$$

- The intensity represents the mean arrival rate: for small Δ

$$\lambda_t \Delta \approx \mathbb{E}(N_{t+\Delta} - N_t \,|\, \mathcal{F}_t)$$

Point process

The characteristic martingale

- Let $\psi(u) = 1 - e^{-u}$ and define

$$Z_t(u) = \exp(\psi(u)A_t - uN_t), \qquad u \geq 0$$

- By Stieltjes integration by parts, $Z(u)$ is a (local) martingale since $M = N - A$ is (local) martingale:

$$Z_t(u) = 1 - \psi(u) \int_0^t Z_{s-}(u) dM_s$$

- If $\mathbb{E}(\exp(A_T)) < \infty$, then $(Z_t(u))_{t \leq T}$ is a martingale

Point process

Poisson and doubly-stochastic Poisson process

- Suppose λ is deterministic: Then, by the martingale property of Z

  $$\mathbb{E}(e^{-u(N_T-N_t)}\,|\,\mathcal{F}_t) = e^{-\psi(u)(A_T-A_t)}$$

  Thus N has independent increments, $N_T - N_t \sim \text{Poi}(A_T - A_t)$, so N is a **Poisson process** (one direction of Watanabe's theorem)

- Suppose λ is allowed to be random, but such that conditional on a path of λ, N is a Poisson process with rate function λ (two-step randomization: **doubly-stochastic Poisson process**): Then

  $$\begin{aligned}\mathbb{E}(e^{-u(N_T-N_t)}\,|\,\mathcal{F}_t) &= \mathbb{E}(\mathbb{E}\{e^{-u(N_T-N_t)}\,|\,\mathcal{F}_t,(\lambda_s)_{t\le s\le T}\}\,|\,\mathcal{F}_t)\\ &= \mathbb{E}(e^{-\psi(u)(A_T-A_t)}\,|\,\mathcal{F}_t)\end{aligned}$$

Point process transform

Measure change

- Since $Z_0(u) = 1$, can use $Z_T(u)$ to define $\mathbb{P}^u \approx \mathbb{P}$ via

$$\mathbb{P}^u(B) = \mathbb{E}(Z_T(u)1_B), \quad B \in \mathcal{F}_T$$

- Each $\mathbb{P}^u$ corresponds to a Laplace transform of A:

$$\mathcal{L}^u(v, t, T) = \mathbb{E}^u(e^{-v(A_T - A_t)} \,|\, \mathcal{F}_t), \quad u, v \geq 0$$

- Obtain the $\mathbb{P}$-Laplace transform of N as

$$\begin{aligned} \mathbb{E}(e^{-u(N_T - N_t)} \,|\, \mathcal{F}_t) &= \mathbb{E}(e^{-\psi(u)(A_T - A_t)} e^{-u(N_T - N_t)} e^{\psi(u)(A_T - A_t)} \,|\, \mathcal{F}_t) \\ &= \mathbb{E}(e^{-\psi(u)(A_T - A_t)} Z_T(u)/Z_t(u) \,|\, \mathcal{F}_t) \\ &= \mathbb{E}^u(e^{-\psi(u)(A_T - A_t)} \,|\, \mathcal{F}_t) \\ &= \mathcal{L}^u(\psi(u), t, T) \end{aligned}$$

Point process transform

Discussion

- The transform of N is given by the $\mathbb{P}^u$-transform of A evaluated at the characteristic exponent $\psi(u)$ of the Poisson process
  - The measure change absorbs any correlation between λ and N, and is therefore called the **correlation-neutral measure**
  - It is redundant in the doubly-stochastic case
- Can be extended to a vector of correlated point processes and to include a stochastic discount factor and random future cash flows, see Giesecke & Zhu (2010)
- Transform of A is analogous to the price at time t of a security that pays 1 at T when the risk-free interest rate is $v\lambda$:

$$\mathcal{L}^u(v,t,T) = \mathbb{E}^u(e^{-\int_t^T v\lambda_s ds} \,|\, \mathcal{F}_t)$$

Point process transform

Laplace transform

- Adopt models for λ from default-free security valuation
  - Affine models, Duffie, Pan & Singleton (2000)
  - Quadratic models, Leippold & Wu (2002)
  - Linear-quadratic models, Cheng & Scaillet (2007)
- Girsanov's theorem implies that
  - The dynamics of any process that does not have jumps in common with N are not adjusted
  - The intensity of N under $\mathbb{P}^u$ is $e^{-u}\lambda$

Affine point process

- Take $\lambda = \Lambda(X)$ for Λ affine
- Under $\mathbb{P}$, the risk factor X solves the SDE

$$dX_t = \mu(X_t)\,dt + \sigma(X_t)\,dW_t + \delta\,dL_t \tag{1}$$

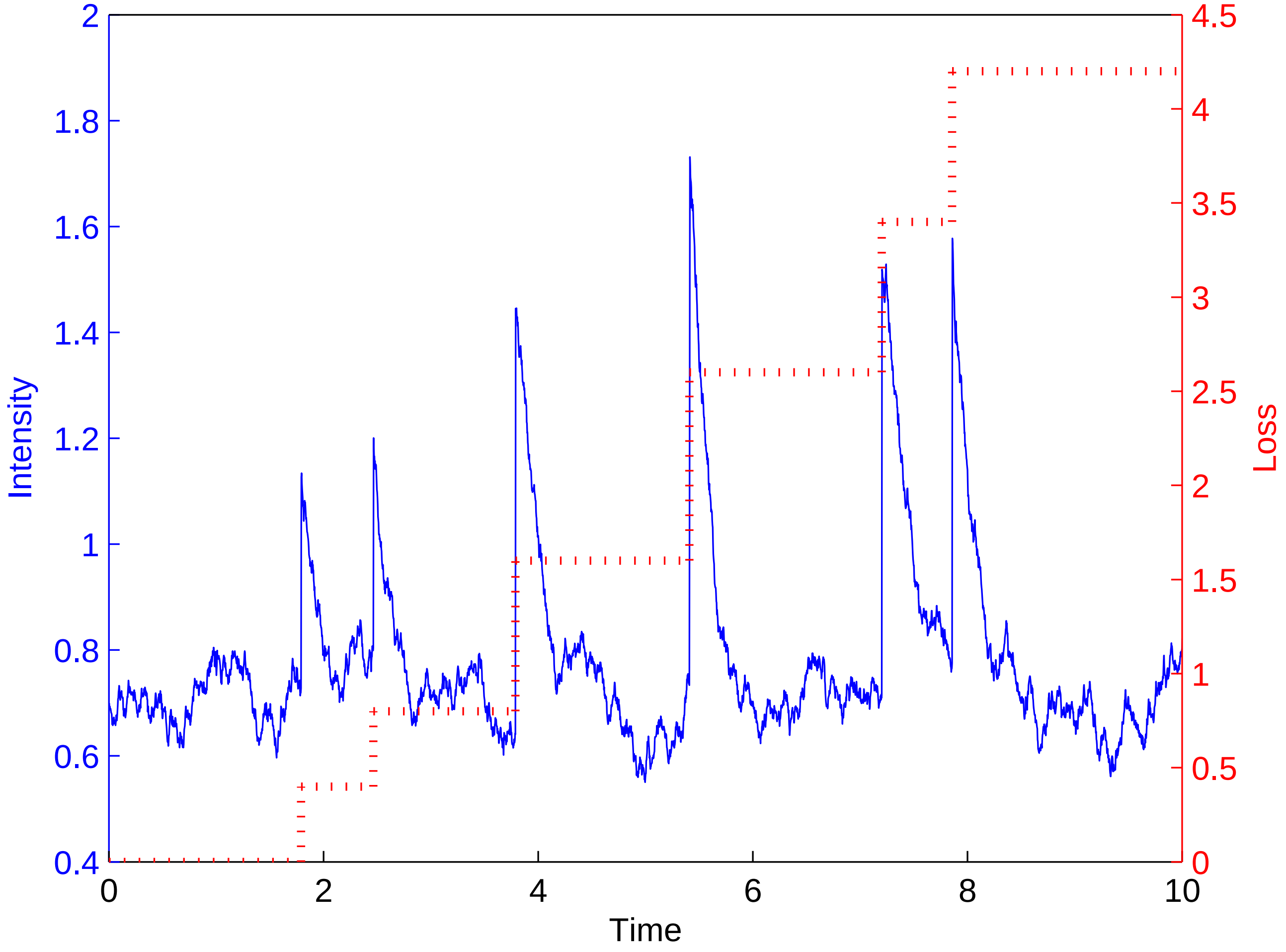
  where μ, σ^2 are affine functions
- $L_t = \sum_{k=1}^{N_t} L^k$ is a (loss) point process whose jump times T^k are those of N; random jump sizes L^k are iid with transform θ
  - Self-exciting model
- From Duffie et al. (2000), know that for R affine

$$\mathbb{E}(e^{-\int_t^T R(X_s)ds + zX_T} \mid \mathcal{F}_t) = e^{a(t)+b(t)X_t}$$

  where $b(t) = b(z,t,T)$ and $a(t) = a(z,t,T)$ satisfy ODEs

Affine point process

Sample path of λ and L



Affine point process

- Under $\mathbb{P}^u$, the intensity is $\lambda e^{-u} = \Lambda e^{-u}$
- Applying the previous result,

$$\mathcal{L}^u(v,t,T) = \mathbb{E}^u(e^{-v\int_t^T \Lambda(X_s)ds} \,|\, \mathcal{F}_t) = e^{\alpha(t)+\beta(t)X_t}$$

where $\beta(t) = \beta(u,v,t,T)$ and $\alpha(t) = \alpha(u,v,t,T)$ satisfy

$$\begin{aligned}\partial_t\beta(t) &= v\Lambda_1 - K_1\beta(t) - \frac{1}{2}H_1\beta(t)^2 - e^{-u}\Lambda_1(\theta(\delta\beta(t)) - 1)\\ \partial_t\alpha(t) &= v\Lambda_0 - K_0\beta(t) - \frac{1}{2}H_0\beta(t)^2 - e^{-u}\Lambda_0(\theta(\delta\beta(t)) - 1)\end{aligned}$$

- The transform of N satisfies

$$\begin{aligned}\mathbb{E}(e^{-u(N_T-N_t)} \,|\, \mathcal{F}_t) &= \mathcal{L}^u(\psi(u),t,T)\\ &= \exp(\alpha(u,\psi(u),t,T) + \beta(u,\psi(u),t,T)X_t)\end{aligned}$$

Point process simulation

Time change

- Meyer's (1971) time change theorem asserts that the variables

$$S^k = A_{T^k} = \int_0^{T^k} \lambda_s ds, \quad k = 1, 2, \ldots, n$$

  are the arrival times of a standard Poisson process in the time-scaled filtration defined by $\mathcal{F}_{A_t}$

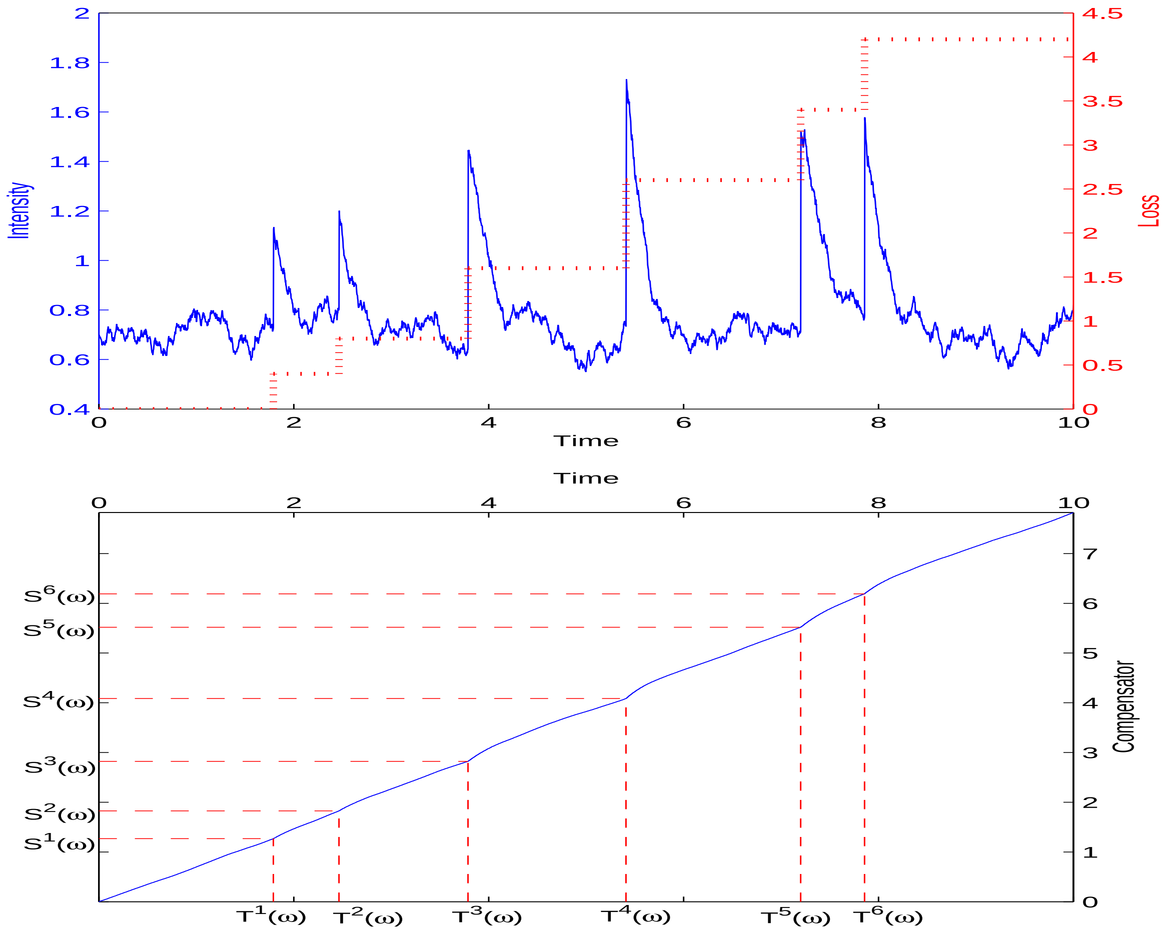
- Conversely, the kth default time is the hitting time of A to the random level S^k

$$T^k = A^{-1}_{S^k} = \inf\left\{t : \int_0^t \lambda_s ds \geq S^k\right\}$$

- Implementation: discretization of λ

Point process simulation

Paths of λ_t, $A_t = \int_0^t \lambda_s ds$ and arrivals for the affine model (1)



Point process simulation

Discussion

- Due to discretization of λ, simulation estimators are biased
  - Magnitude of bias is hard to quantify
  - Difficult to obtain valid confidence intervals
  - Difficult to determine optimal allocation of computational budget
- **Exact methods** eliminate the need to discretize λ
  - Thinning scheme: Lewis & Shedler (1979), Glasserman & Merener (2003) for bounded λ and Giesecke, Kim & Zhu (2010) for general case
  - Projection method: Giesecke, Kakavand & Mousavi (2010)
  - Mimicking Markov chain method: Giesecke, Kakavand, Mousavi & Takada (2010)

Valuation

Alternative formulations of the pricing problem

- Model the point process N under the **actual measure** that represents the empirical likelihood of events, and then specify the change of measure to a risk-neutral measure
  - Pricing and empirical time series applications that require risk premia specifications (as in Berndt, Douglas, Duffie, Ferguson & Schranz (2005), Eckner (2007), and Azizpour, Giesecke & Kim (2011))
- Model the point process N under a **risk-neutral measure**
  - Pricing applications

Single-name valuation

- Let $\mathbb{P}$ be a pricing measure relative to a constant risk-free rate r
- The issuer's default time is the first jump time T^1 of N; the corresponding default process is $N^1 = \min(N, 1)$
- The financial loss at default is modeled by an $\mathcal{F}_{T^1}$-measurable random variable ℓ^1, which is independent of T^1 and has $\ell = \mathbb{E}(\ell^1)$
- At any time $t < \min(T, T^1)$, the firm's risk-neutral conditional survival probability satisfies

$$\begin{aligned}\mathbb{P}(T^1 > T \,|\, \mathcal{F}_t) = \mathbb{P}(N_T = 0 \,|\, \mathcal{F}_t) &= \lim_{u \uparrow \infty} \mathcal{L}^u(\psi(u), t, T) \\ &= \mathbb{E}^\infty(e^{-(A_T - A_t)})\end{aligned}$$

where $\mathbb{P}^\infty(T^1 > T) = 1$

Corporate zero bond

A zero coupon bond with unit face value and maturity T pays

- The **face value** 1 at $T < T^1$
  This has value $F(t,T)\mathbb{P}(T^1 > T \,|\, \mathcal{F}_t)$, where $F(t,T)$ is the price of a unit face value, T-maturity zero coupon government bond

- The **recovery** $(1-\ell^1)$ of face value at $T^1 \leq T$
  This has value

$$\mathbb{E}(F(t,T^1)(1-\ell^1)N^1_T \,|\, \mathcal{F}_t) = (1-\ell)R_t(T)$$

where $R_t(T)$ is the pre-default value of a unit recovery payment at $T^1 \leq T$. By Stieltjes integration by parts

$$\begin{aligned} R_t(T) &= \mathbb{E}\left(\int_t^T F(t,s)dN^1_s \,\Big|\, \mathcal{F}_t \right) \\ &= F(t,T)\mathbb{P}(T^1 \leq T \,|\, \mathcal{F}_t) + r\int_t^T F(t,s)\mathbb{P}(T^1 \leq s \,|\, \mathcal{F}_t)ds \end{aligned}$$

Corporate coupon bond

A corporate coupon bond with unit face value, annualized coupon rate c, coupon dates (t_m) and maturity T pays

- The **coupon** cC_m at each $t_m < T^1$ where C_m is the day count fraction for period m ($=$ portfolio of zero-recovery zero bonds)
- The **face value** 1 at $T < T^1$ ($=$ zero-recovery zero bond)
- The **recovery** $(1 - \ell^1)$ of face value at $T^1 \leq T$
- The **accrued coupon** $\frac{T^1 - t_{m-1}}{\Delta_m} cC_m$ at T^1 if $t_{m-1} < T^1 \leq t_m$, where $\Delta_m = t_m - t_{m-1}$

Its pre-default value is given by

$$F(t,T)\mathbb{P}(T^1 > T \,|\, \mathcal{F}_t) + cV_t(T) + (1-\ell)R_t(T)$$

where $V_t(T)$ is the *risky DV01*, the pre-default value of a unit stream at coupon times (t_m) until $\min(T^1, T)$ plus any accruals

Credit swap

A credit swap with unit notional, annualized swap spread S, premium payment dates (t_m) and maturity T is a bilateral contract in which

- The **protection seller** pays the default loss ℓ^1 at $T^1 \leq T$
  This has pre-default value $D_t = \ell R_t(T)$
- The **protection buyer** pays the swap spread SC_m at each $t_m < T^1$ plus any accruals
  This has pre-default value $P_t(S) = SV_t(T)$

The fair spread S equates the values of the default and premium legs. Since there is no cash flow at inception, the fair swap spread at inception date t is the solution $S = S_t(T)$ to the equation $D_t = P_t(S)$:

$$S_t(T) = \ell R_t(T)/V_t(T)$$

Credit swap

Notes

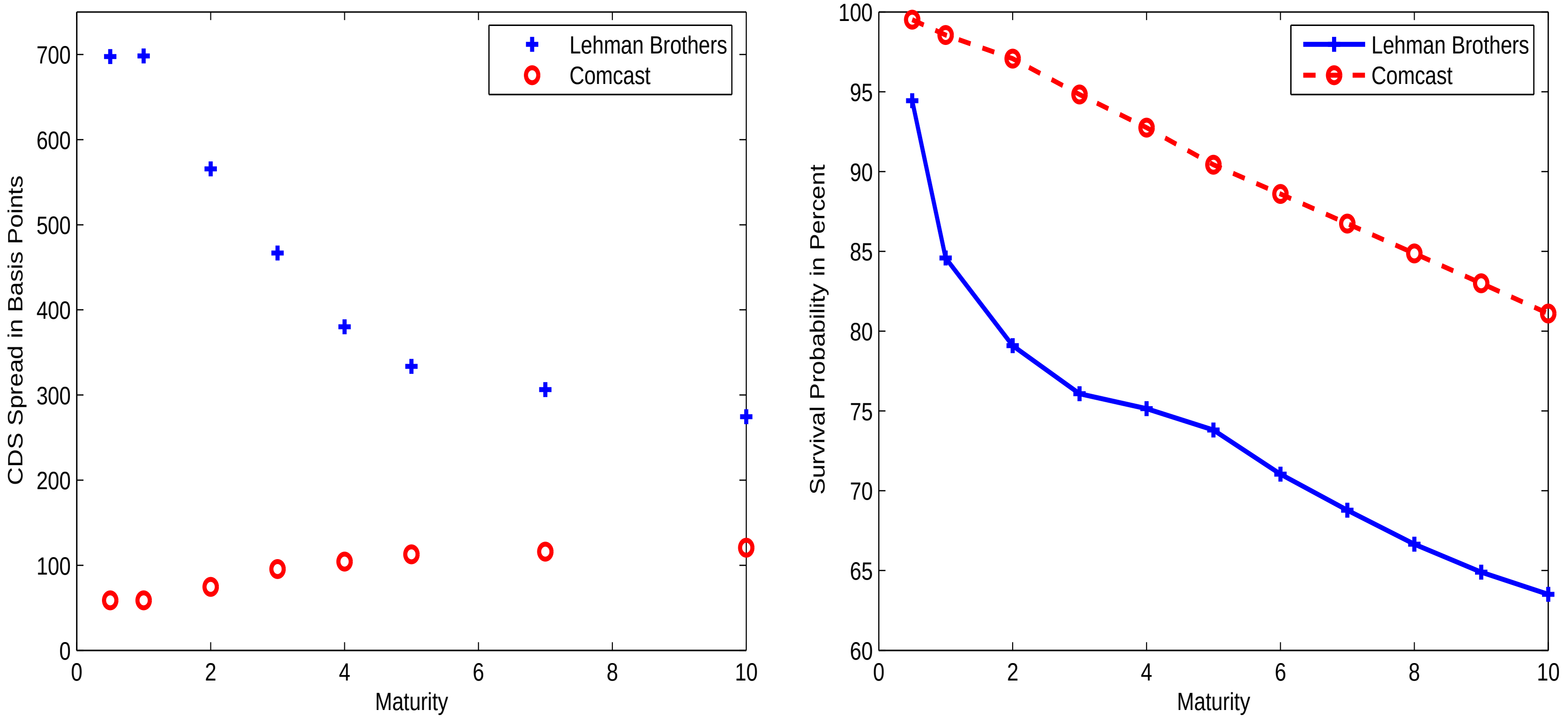
- $S_t(T)$ can be expressed in terms of $\mathbb{P}(T^1 > s \,|\, \mathcal{F}_t)$ for various $s \leq T$, and the expected loss ℓ
- Often traded in terms of points upfront
- We have ignored **counterparty risk**, the risk that the protection seller fails with the reference entity
- Consider an investor who buys protection at $t = 0$ for the period $[0, T]$ at a swap spread of $S_0(T)$. The **mark-to-market value** of the position at time $t \geq 0$, when the market spread is $S_t(T)$, is

$$V_t(T)(S_t(T) - S_0(T)) = D_t - P_t(S_0(T))$$

- Forward CDS and swaption: contracts on the mark-to-market

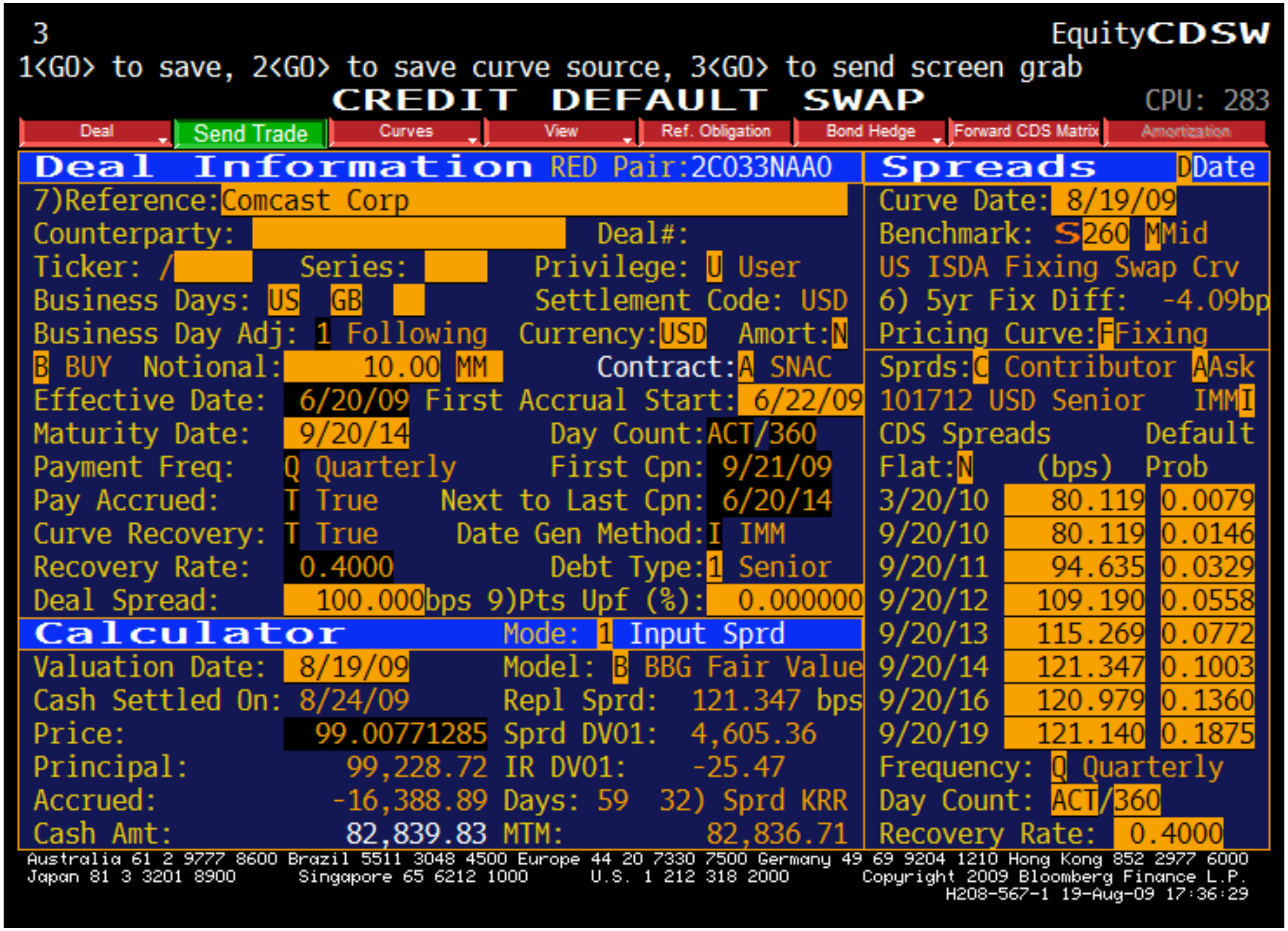
Credit swap

Market spreads on 9/8/2008 and implied $\mathbb{P}(T^1 > T)$ for two firms, assuming piece-wise constant intensity λ and $\ell = 0.6$



Credit swap

Bloomberg CDSW



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7)Reference:Comcast Corp                    Curve Date: 8/19/09
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B BUY  Notional:      10.00 MM        Contract:A SNAC  Sprds:C Contributor AAsk
Effective Date:  6/20/09 First Accrual Start: 6/22/09  101712 USD Senior   IMMI
Maturity Date:   9/20/14          Day Count:ACT/360  CDS Spreads       Default
Payment Freq:    Q Quarterly      First Cpn: 9/21/09  Flat:N    (bps)   Prob
Pay Accrued:     T True     Next to Last Cpn: 6/20/14  3/20/10     80.119 0.0079
Curve Recovery:  T True      Date Gen Method:I IMM     9/20/10     80.119 0.0146
Recovery Rate:   0.4000           Debt Type:1 Senior   9/20/11     94.635 0.0329
Deal Spread:      100.000bps 9)Pts Upf (%):  0.000000  9/20/12    109.190 0.0558
Calculator              Mode: 1 Input Sprd             9/20/13    115.269 0.0772
Valuation Date:  8/19/09      Model: B BBG Fair Value  9/20/14    121.347 0.1003
Cash Settled On: 8/24/09      Repl Sprd:  121.347 bps  9/20/16    120.979 0.1360
Price:            99.00771285 Sprd DV01:  4,605.36     9/20/19    121.140 0.1875
Principal:          99,228.72 IR DV01:     -25.47      Frequency: Q Quarterly
Accrued:           -16,388.89 Days: 59  32) Sprd KRR   Day Count: ACT/360
Cash Amt:           82,839.83 MTM:          82,836.71  Recovery Rate:  0.4000
Australia 61 2 9777 8600 Brazil 5511 3048 4500 Europe 44 20 7330 7500 Germany 49 69 9204 1210 Hong Kong 852 2977 6000
Japan 81 3 3201 8900       Singapore 65 6212 1000       U.S. 1 212 318 2000       Copyright 2009 Bloomberg Finance L.P.
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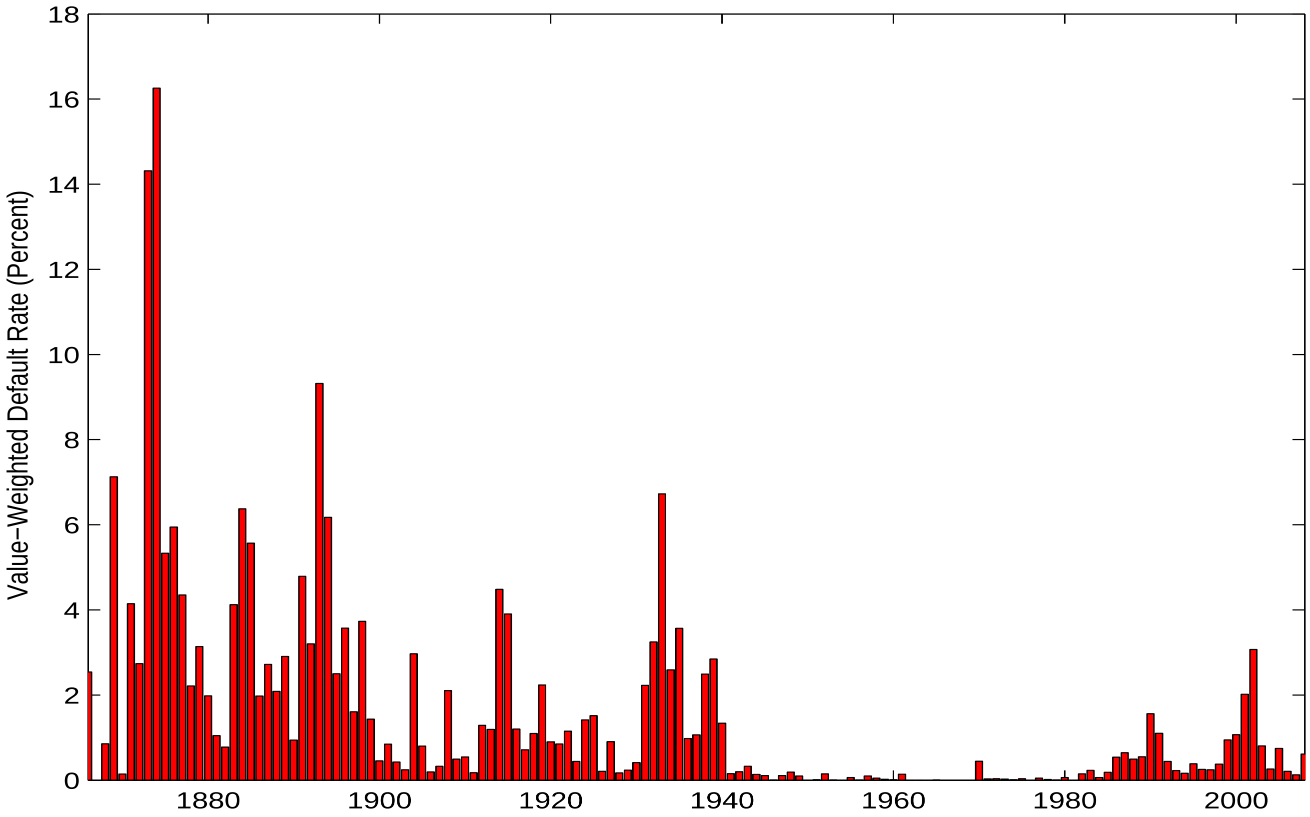
Corporate defaults cluster

Value-weighted default rate 1865–2008, US nonfinancial (Source: Giesecke, Longstaff, Strebulaev & Schaefer (2011))



Sources of default clustering

- First, firms are exposed to **common or correlated risk factors**. The movements of these factors cause correlated changes in firms' conditional default rates (Duffie, Saita & Wang (2006))
- Second, some of the risk factors may be unobservable **frailties**. The uncertainty regarding the values of these factors has an influence on the conditional default rates of the firms that depend on the same frailties (Duffie, Eckner, Horel & Saita (2009))
- Third, a default may be **contagious**, and have a direct impact on the conditional default rates of other firms (Azizpour, Giesecke & Schwenkler (2009))

Portfolio derivatives

- They facilitate the transfer of the correlated default risk in a portfolio of names
  - There are multiple families of standard reference portfolios, called indices, including the CDX family (North American issuers) and the iTraxx family (European and Asian names)
- They are contingent claims on the portfolio loss point process $L = \sum_{k=1}^{N} \ell^k$ where ℓ^k is the loss at the kth default
- The reference pool often consists of single-name CDS with common notional that we normalize to 1, common maturity date T and common premium payment dates (t_m).
- We pursue a **top-down approach**, modeling the intensity λ of N without reference to the n portfolio constituents

Index swap

In an index swap with swap spread S and maturity T,

- The **protection seller** covers portfolio losses as they occur, i.e. the increments of L; this leg has value

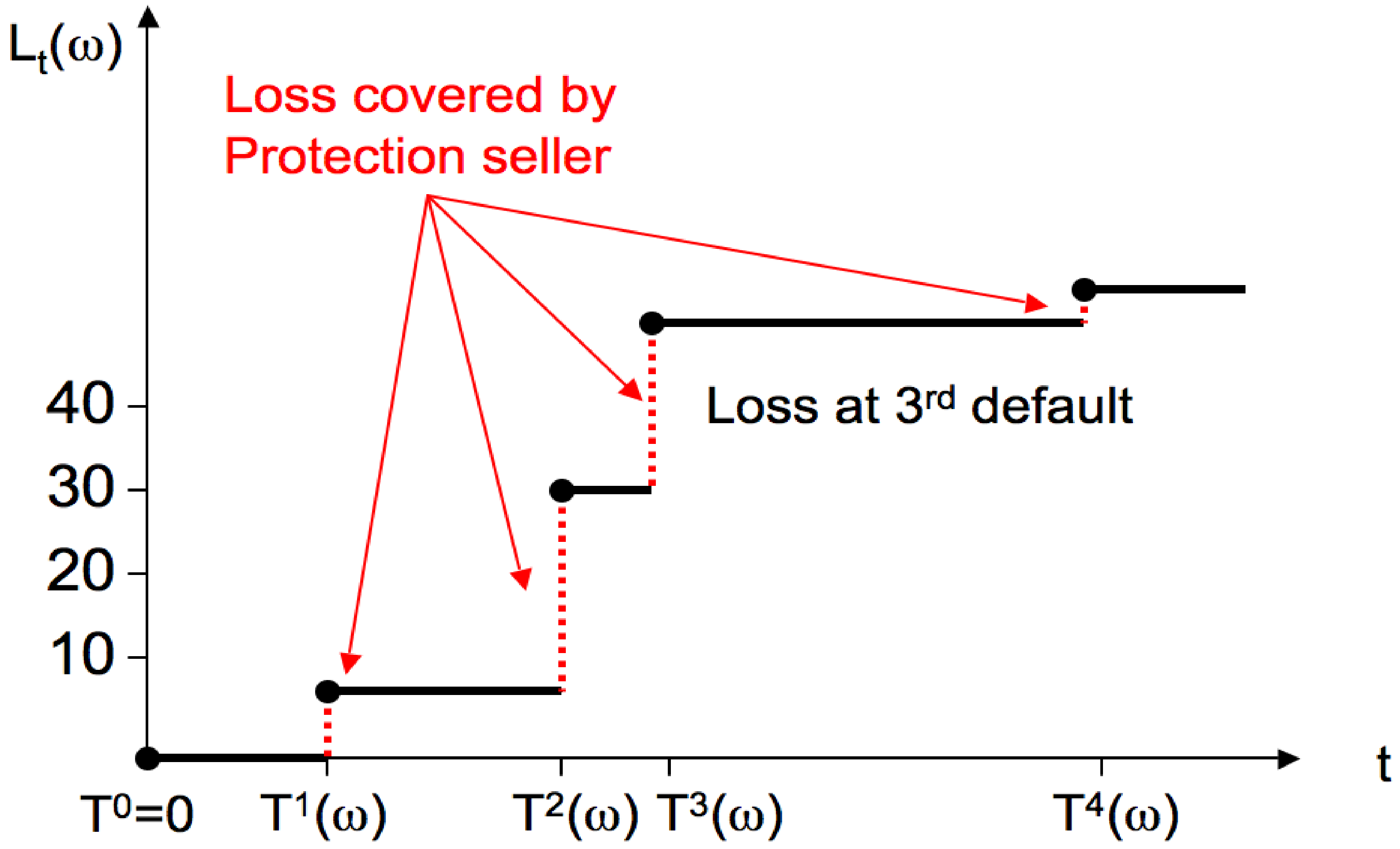
$$D_t = \mathbb{E}\left(\int_t^T F(t,s) dL_s \,\middle|\, \mathcal{F}_t \right)$$
$$= F(t,T)\mathbb{E}(L_T \,|\, \mathcal{F}_t) - L_t + r \int_t^T F(t,s)\mathbb{E}(L_s \,|\, \mathcal{F}_t)\, ds$$

- The **protection buyer** pays $SC_m(n - N_{t_m})$ at each date t_m; this leg has value

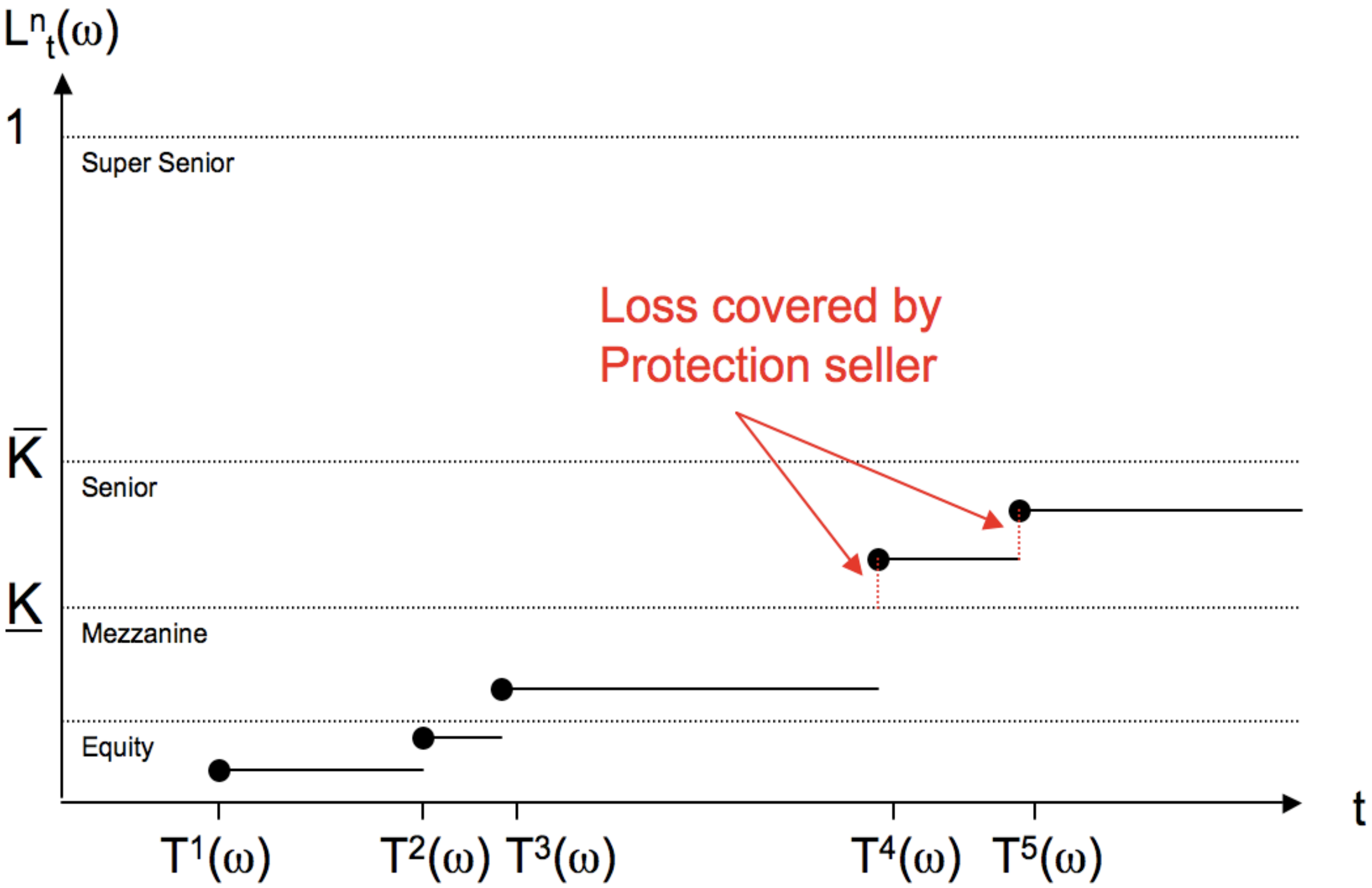
$$P_t(S) = S \sum_{t_m \geq t} F(t,t_m) C_m (n - \mathbb{E}(N_{t_m} \,|\, \mathcal{F}_t))$$

The fair index swap spread at time t is the solution $S = S_t(T)$ to the equation $D_t = P_t(S)$

Index swap default leg

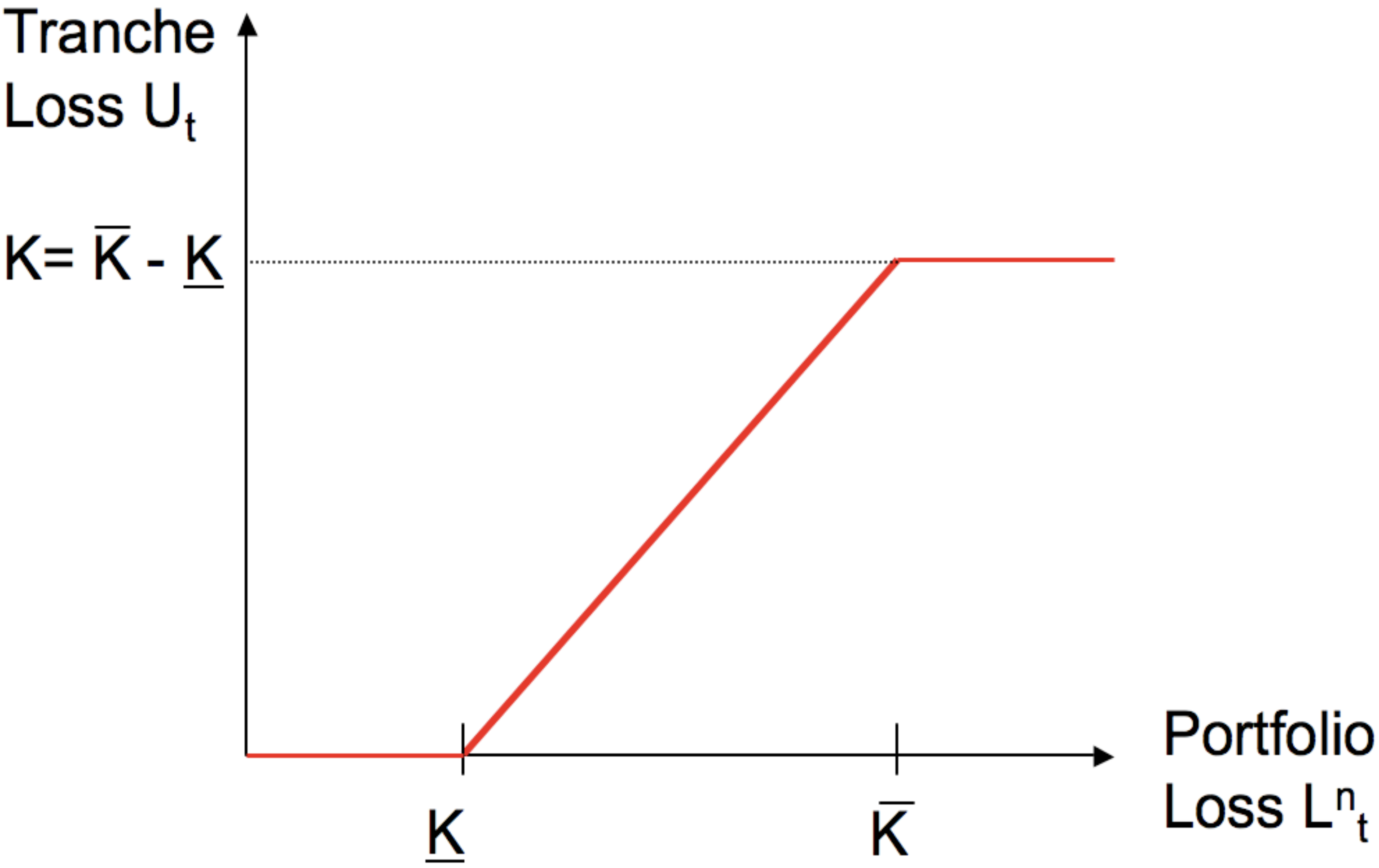


Tranche swap default leg



Loss covered by Protection seller

Tranche loss = call spread on portfolio loss



Tranche swap

In a tranche with lower attachment point $\underline{K} \in [0,1]$, upper attachment point $\overline{K} \in (\underline{K}, 1]$, upfront rate G, and swap spread S,

- The **protection seller** covers tranche losses $U_t = (L_t - \underline{K}n)^+ - (L_t - \overline{K}n)^+$ as they occur; this has value

$$D_t(\underline{K}, \overline{K}) = F(t,T)\mathbb{E}(U_T \,|\, \mathcal{F}_t) - U_t + r\int_t^T F(t,s)\mathbb{E}(U_s \,|\, \mathcal{F}_t)\, ds$$

- The **protection buyer** pays GKn at inception and $SC_m(Kn - U_{t_m})$ at each date t_m (assuming $\overline{K} < 1$)

$$P_t(\underline{K}, \overline{K}, G, S) = GKn + S\sum_{t_m \geq t} F(t,t_m)C_m(Kn - \mathbb{E}(U_{t_m} \,|\, \mathcal{F}_t))$$

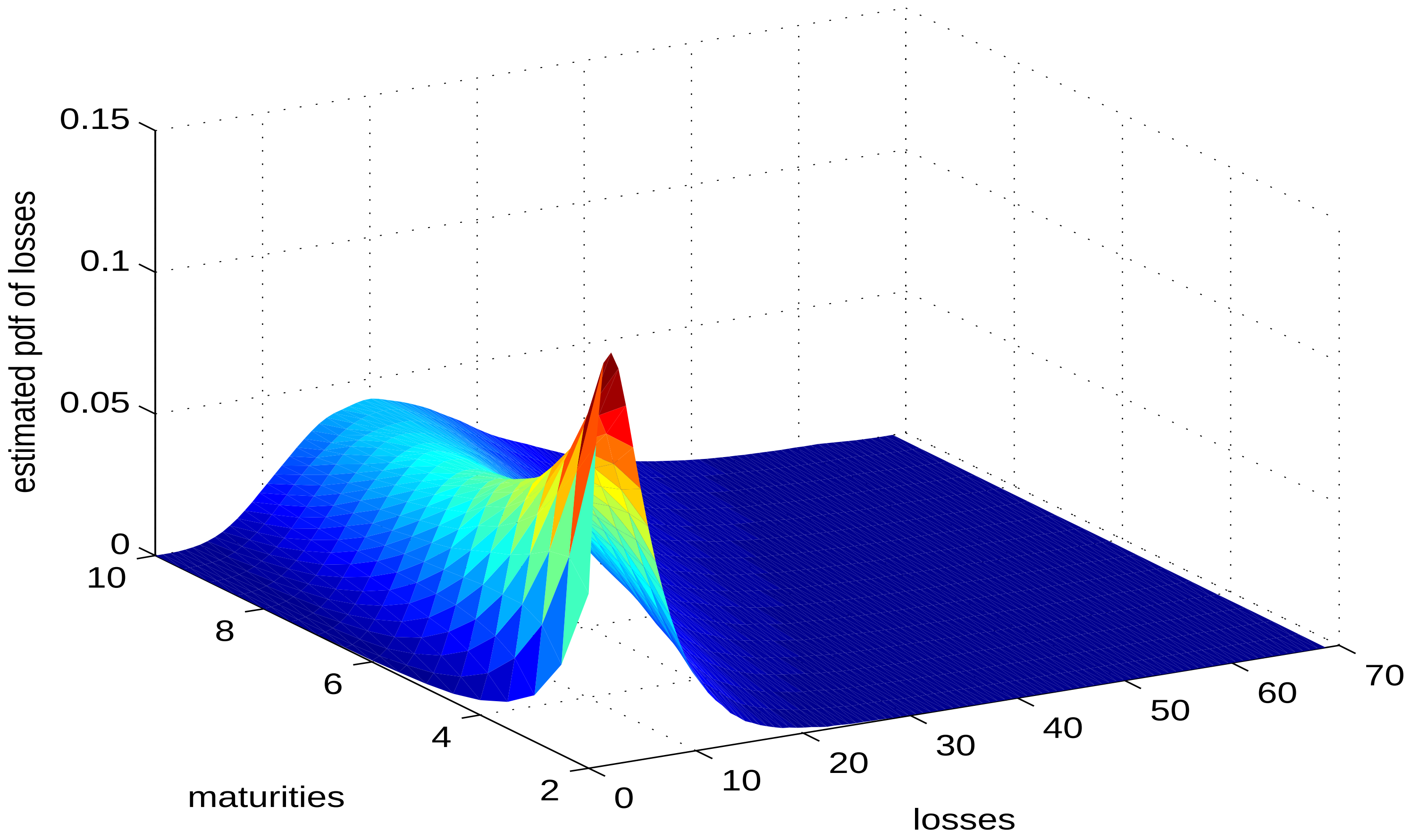
For fixed G, the fair spread S is the solution $S = S_t(\underline{K}, \overline{K}, G, T)$ to $D_t(\underline{K}, \overline{K}) = P_t(\underline{K}, \overline{K}, G, S)$. For fixed S, the fair upfront rate G is the solution $G = G_t(\underline{K}, \overline{K}, S, T)$ to $D_t(\underline{K}, \overline{K}) = P_t(\underline{K}, \overline{K}, G, S)$.

Market calibration

Calibrating the affine model (1) to the CDX.HY on 5/11/2007, with $\lambda = X$, where $dX_t = \kappa(c - X_t)dt + \sigma\sqrt{X_t}dW_t + \delta dL_t$, the ℓ^k iid uniform on $\{a, b\}$ with $\mathbb{E}(\ell^k) = 0.6$

Contract	MarketBid	MarketAsk	Model
0-10%	70.50%	70.75%	71.11%
10-15%	34.25%	34.50%	32.85%
15-25%	316.00	319.00	316.80
25-35%	79.00	81.00	81.47
Index	262.85	263.10	263.46
AAPE			1.47%

Market implied loss surface



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