Credit risk

Part 6 of Credit Products Playground

danieltuzes

Content with changes after version 0.4.0, not yet released
https://danieltuzes.github.io/credit-and-derivatives/

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Part 6

Credit risk

Part 1 gave events and expectations over a partition, present value, and risk-neutral pricing weights. This part applies them to a new event, the default of a reference entity. Default and survival partition the outcomes at each future date, so a survival curve gives default probabilities, and a risky payment is valued as a discounted expectation over the survival and default states.

This part introduces the default time of a reference entity in the course's toy models. The first chapter reads an input survival curve, calculates the default probability of each interval, and uses a constant hazard rate. The second chapter values one claim under recovery of par: it pays its full amount on survival and a recovered fraction of par on default, both at maturity, and the claim's value is the discounted expectation of those two payments.

The argument

1. The default time is random, and survival to a date is an event
2. A survival curve gives the default probability of each interval
3. A constant hazard rate gives an exponential survival curve
4. Recovery of par sets the payment in the default state
5. A risky payment is the discounted expectation over survival and default

After this part you can

- Interpret survival probability as the modeled probability, conditional on survival at valuation time, of no default through a stated future time.
- Calculate time-zero cumulative or interval default probability from survival probabilities at stated times.
- Interpret a hazard rate as an instantaneous conditional default intensity, measured per unit of time, among names that have survived to that time.
- Calculate survival probability as S(0,t) = exp(-lambda t) under a stated non-negative constant hazard rate and consistent time units.
- Interpret the recovery rate as the fraction of par paid at maturity after default in the lesson's one-period recovery-of-par model.
- Calculate loss given default as one minus the recovery rate in the lesson's fractional recovery-of-par model.
- Calculate the time-zero present value of a one-period recovery-of-par claim by probability-weighting its survival and default payoffs at maturity and applying the stated discount factor.

Builds on

- Foundations

Leads to

- Bond options
- CDS

Chapter 6.1

Default, hazard, and survival

Interactive version: https://danieltuzes.github.io/credit-and-derivatives/credit/default-hazard-and-survival

6.1.1 What you will be able to do

After this lesson, you should be able to:

- interpret a survival probability without confusing it with a discount factor;
- calculate the default probability of one interval from the survival curve;
- explain what a constant hazard rate means in this toy model;
- calculate the survival probability from a constant hazard rate.

6.1.2 Survival probability: no default by time t

The survival-probability $S^{\mathbb{Q}}(0,t)$ is the probability, under the risk-neutral-probability-measure $\mathbb{Q}$, that the reference entity has not defaulted between valuation-time 0 and a future time-from-valuation t. With the default-time τ, the survival probability is defined as:

$$S^{\mathbb{Q}}(0,t) = \mathbb{Q}(\tau > t) \tag{6.1.1}$$

In this lesson, the survival probabilities are inputs: the lesson states their values and does not calculate them. In practice, a survival curve is fitted to market prices. The CDS lesson on the credit curve fits one to CDS quotes.

A survival probability is not a discount factor. A survival probability is the probability of a modeled event. A discount factor converts an amount paid at a future time to its value at time zero. A survival probability and a discount factor can have equal values and still mean different things.

We assume that the survival curve starts at one:

$$S(0,0) = 1 \tag{6.1.2}$$

We also assume that the survival curve does not increase with time. This lesson does not estimate survival probabilities from historical data, and it does not fit them to market quotes. Tuckman and Serrat introduce survival and default probabilities for CDS valuation[1]. Hull distinguishes risk-neutral default probabilities, which are used in valuation, from real-world default probabilities [2].

6.1.3 Interval default probability: a decrease in survival

The local credit-period-index i selects one interval of the survival schedule, and the number-of-credit-periods n counts the intervals. Interval i starts at t_{i-1} and ends at the payment-time t_i, with $t_{i-1} < t_i$. The interval-default-probability of interval i is the decrease in survival probability over the interval:

$$\Delta q_i^{\mathbb{Q}} = S^{\mathbb{Q}}(0, t_{i-1}) - S^{\mathbb{Q}}(0, t_i) \tag{6.1.3}$$

The survival probability at the start of the interval comes first in the subtraction. Because the survival curve does not increase, this order gives $\Delta q_i \geq 0$. The sum of the interval default probabilities from time zero to t_n is the cumulative default probability by t_n:

$$\sum_{i=1}^{n} \Delta q_i = 1 - S(0, t_n) \tag{6.1.4}$$

This identity holds because the sum telescopes: each intermediate survival probability appears once with a plus sign and once with a minus sign. The identity uses two assumptions: $S(0,0) = 1$, and at most one modeled default.

6.1.4 Constant hazard rate: an intensity, not a cumulative probability

In this lesson, the Constant hazard rate λ is constant. It is a conditional default intensity, measured per model-year. The hazard rate is not the probability of default by the end of one year. It is also not a discount rate. With the local credit-small-time-increment Δt, the hazard rate is defined as the limit of a conditional default probability per unit of time:

$$\lambda = \lim_{\Delta t \downarrow 0} \frac{\mathbb{Q}(t < \tau \leq t + \Delta t \mid \tau > t)}{\Delta t} \tag{6.1.5}$$

The probability in this definition is conditional on the event $\tau > t$. So the hazard rate at time t describes only the paths on which the reference entity has survived to t.

With a constant hazard rate, the survival probability is:

$$S^{\mathbb{Q}}(0, t) = \exp(-\lambda t) \tag{6.1.6}$$

So the cumulative default probability by t is $1 - S(0, t)$. This lesson does not introduce piecewise hazard rates, curve calibration, or a statistical estimator. Tuckman and Serrat derive the conditional intensity and the constant-hazard survival probability[3], and so does Hull [4].

Example 6.1.1: Survival and default probabilities

One interval drop

Suppose the one-year survival probability is $S(0,1) = 0.97$. With $S(0,0) = 1$, the interval default probability of the first year is:

$$\Delta q_1 = 1 - 0.97 = 0.03 = 3\%$$

The 3% is the probability of default during the first year. It is not discounted.

Three years at constant hazard

Let $\lambda = 0.02$ per model-year and $t = 3$ model-years. Substituting these values into (6.1.6) gives the three-year survival probability:

$$S(0,3) = \exp(-0.02 \times 3) = \exp(-0.06) \approx 0.941765$$

The cumulative default probability by three years is:

$$1 - S(0,3) \approx 0.058235 = 5.8235\%$$

The cumulative default probability is not $\lambda t = 6\%$. The product λt is the exponent in the survival probability. It is not the exact cumulative default probability.

Two unequal interval drops

Consider this survival curve:

Interval index i	Time t_i, model-years	Survival $S(0,t_i)$	Interval default Δq_i
0	0	1.00	—
1	1	0.97	0.03
2	2	0.92	0.05

The interval default probability of the second interval, 0.05, is larger than that of the first interval, 0.03, although both intervals are one model-year long. The cumulative two-year default probability is $0.03 + 0.05 = 0.08 = 1 - 0.92$.

6.1.5 Check your understanding

The assessment separates survival meaning, interval subtraction, hazard interpretation, and constant-hazard arithmetic. Each competency has a direct item and a transfer item.

Knowledge check 6.1.1: Default, hazard, and survival

1. A model gives S(0,3) = 0.92 for a name that has survived to valuation time 0. Which interpretation is correct?
   (a) The modeled probability of no default through year 3 is 92%
   (b) The modeled probability of default by year 3 is 92%
   (c) The three-year discount factor is necessarily 0.92
2. Under the same model and valuation time, name A has five-year survival probability 0.84 and name B has five-year survival probability 0.93. Which conclusion is supported?
   (a) Name A has the larger modeled probability of default by year 5
   (b) Name B has the larger modeled probability of default by year 5
   (c) The two names have the same modeled probability of default by year 5
3. A model gives two-year survival probability S(0,2) = 0.93. Enter the cumulative probability of default by year 2 as a decimal.

4. Viewed from valuation time 0, survival probabilities are S(0,1) = 0.97 and S(0,2) = 0.91. Enter the unconditional probability of default during the interval from year 1 to year 2 as a decimal.

5. In the lesson model, what does a hazard rate at time t describe?

   (a) Instantaneous default intensity conditional on survival to time t

   (b) Cumulative default probability from time 0 through time t

   (c) The interest rate used to discount every cash flow

6. Two names have survived to the same instant. Name A's current hazard rate is 2% per year and name B's is 5% per year. Over the next very short interval, which statement matches the hazard interpretation?

   (a) Name B has the higher modeled conditional default likelihood

   (b) Name A has the higher modeled conditional default likelihood

   (c) The rates alone prove both names have already defaulted

7. Under the constant-hazard exponential model, calculate the dimensionless three-year survival probability for an annual hazard rate of 2% (0.02 per year).

8. Under the constant-hazard exponential model, calculate the dimensionless survival probability over 18 months for an annual hazard rate of 3.2% (0.032 per year).

Answers: *end of the chapter.*

6.1.6 Model boundary and review note

This lesson uses a toy model with at most one default, a constant hazard rate, exact model-year times, and survival probabilities that are inputs. The model omits:

- calendar dates, day counts, and business-day adjustments;
- stochastic interest rates;
- dependence between interest rates and default;
- estimation and calibration.

The lesson makes no claim that pricing-model probabilities are forecasts of realized default frequencies.

All materially changed source locators, formulas, examples, notation, and answer keys remain 'draft' pending independent human review.

References

[1] Tuckman & Serrat, Fixed Income Securities: Tools for Today's Markets (4th ed., 2022). Ch. 14 §14.6, printed pp. 367–370, eqs. 14.4–14.7.

[2] Hull, Options, Futures, and Other Derivatives (8th ed., 2012). Ch. 23 §23.5, printed pp. 528–530.

[3] Tuckman & Serrat, Fixed Income Securities: Tools for Today's Markets (4th ed., 2022). Ch. 14 §14.6, printed pp. 367–368; Appendix A14.1, printed p. 505, eqs. A14.1–A14.2.

[4] Hull, Options, Futures, and Other Derivatives (8th ed., 2012). Ch. 23 §§23.2 and 23.5, printed pp. 522–523 and 528–530.

Answers to the knowledge checks

Knowledge check 6.1.1: Default, hazard, and survival

1. **(a)** The modeled probability of no default through year 3 is 92%. S(0,3) is the model's probability, conditional on survival at valuation time, that no default occurs through year 3.

2. **(a)** Name A has the larger modeled probability of default by year 5. Lower survival to the same horizon implies higher cumulative default probability to that horizon: 1 - 0.84 exceeds 1 - 0.93.

3. 0.07 (accepted within $\pm 1e-12$). Cumulative default probability is 1 - S(0,2) = 1 - 0.93 = 0.07.

4. 0.06 (accepted within $\pm 1e-12$). The interval default probability is S(0,1) - S(0,2) = 0.97 - 0.91 = 0.06.

5. **(a)** Instantaneous default intensity conditional on survival to time t. Hazard is an instantaneous conditional intensity with inverse-time units, not a cumulative probability or discount rate.

6. **(a)** Name B has the higher modeled conditional default likelihood. Conditional on both names having survived to the instant, the higher current hazard corresponds to greater modeled default likelihood over a sufficiently short next interval.

7. 0.941764533584249 (accepted within ±0.000001). S(0,3) = exp(-0.02 × 3) = exp(-0.06) = 0.9417645336.

8. 0.953133787077505 (accepted within ±0.000001). Eighteen months is 1.5 years, so survival is exp(-0.032 × 1.5) = exp(-0.048) = 0.9531337871.

Chapter 6.2

Recovery and one-period risky present value

Interactive version: https://danieltuzes.github.io/credit-and-derivatives/credit/recovery-and-risky-present-

6.2.1 What you will be able to do

After this lesson, you should be able to:

- interpret recovery as a fraction of a named base paid at a named time;
- calculate loss given default as the complement of recovery;
- calculate present value in one explicitly labeled recovery-of-par-paid-at-maturity model.

6.2.2 Name the recovery convention before calculating

This lesson uses one recovery convention. A claim has a positive local recovery-par-amount F and one local recovery-payment-time T, measured from valuation-time 0.

- If the reference entity survives through T, the holder receives F at T.
- If the reference entity defaults at or before T, the holder receives RF at T, where the recovery-rate R is deterministic.

The survival payment and the default payment are both paid at T. This timing is a model assumption, not a description of an actual instrument. This lesson does not teach recovery paid at default, recovery of market value, settlement delay, or a CDS settlement mechanism.

Tuckman and Serrat define a bond recovery rate relative to the face amount. They also identify the complementary loss fraction in their credit-loss discussion [1]. Payment of the recovery at maturity is a convention of this lesson. The lesson does not claim that it is the only recovery convention.

6.2.3 Recovery and loss given default are complements here

The loss-given-default fraction is defined as:

$$\text{LGD} = 1 - R, \qquad 0 \leq R \leq 1 \tag{6.2.1}$$

For example, $R = 0.40$ gives $\text{LGD} = 0.60$ in this toy model. The value 0.40 is chosen only for the arithmetic. The lesson makes no claim that 40% is a market convention, a forecast, or an appropriate assumption for any real entity.

6.2.4 Calculate the expected maturity amount, then discount it

The input survival-probability is $S^{\mathbb{Q}}(0,T)$ under the risk-neutral-probability-measure $\mathbb{Q}$. In the one-default model, the probability of default by T is $1 - S^{\mathbb{Q}}(0,T)$.

For the single interval from 0 through T, $1 - S(0,T)$ is the interval-default-probability. The expected amount paid at T under $\mathbb{Q}$ is the survival payment and the default payment, each multiplied by its probability:

$$F\left[S\left(0,T\right) + R\left(1 - S\left(0,T\right)\right)\right] \tag{6.2.2}$$

This is the two-event case of the expectation from disjoint events in the probability lesson: survival pays F, and default pays RF. Shreve gives the expectation of a finite-valued random variable[2]. Tuckman and Serrat weight credit cash flows by survival and default probabilities and then discount them[3].

The survival payment and the default payment are both paid at T. So one input discount-factor $D(0,T)$ applies to both. The recovery-of-par-present-value is the discounted expected amount:

$$PV_0^{\text{RoP}} = F\,D(0,T)\left[S^{\mathbb{Q}}\left(0,T\right) + R\left(1 - S^{\mathbb{Q}}\left(0,T\right)\right)\right] \tag{6.2.3}$$

This present-value is calculated from the perspective of the holder of the claim: the modeled future receipts and their value are positive. A purchase price paid by the holder would have the opposite cash-flow sign.

Example 6.2.1: Recovery-of-par present values

Partial recovery

Let $F =$ USD 1,000, $D(0,T) = 0.96$, $S(0,T) = 0.92$, and $R = 0.40$. The expected fraction of par paid at maturity is:

$$0.92 + 0.40(1 - 0.92) = 0.952$$

Multiplying this fraction by the par amount and the discount factor gives the present value:

$$PV_0^{\text{RoP}} = 1000(0.96)(0.952) = \text{USD } 913.92$$

The expected amount at maturity, before discounting, is USD 952.00. The discount factor converts this amount to its value at valuation time.

Zero-recovery boundary

Let $F =$ USD 1,000, $D(0,T) = 0.94$, $S(0,T) = 0.90$, and $R = 0$. The default payment is zero, so the present value is:

$$PV_0^{\text{RoP}} = 1000(0.94)\left[0.90 + 0\,(0.10)\right] = \text{USD } 846.00$$

With zero recovery, the present value is the discounted expected survival payment. This example makes no statement about real recovery outcomes.

Full-recovery boundary

Keep $F = \text{USD } 1{,}000$, $D(0,T) = 0.94$, and $S(0,T) = 0.90$, but set $R = 1$. The survival payment and the default payment are now both the full par amount, paid at T:

$$PV_0^{\text{RoP}} = 1000(0.94)\left[0.90 + 1\,(0.10)\right] = \text{USD } 940.00$$

With full recovery, the present value does not depend on the survival probability. The reason is that both modeled events pay the same amount on the same date. This result holds only under the timing convention of this lesson.

6.2.5 Check your understanding

The assessment tests the meaning of recovery, loss-given-default arithmetic, and direct and transfer calculations under the same one-period timing convention.

Knowledge check 6.2.1: Recovery and risky present value

1. In the lesson's one-period recovery-of-par model, what does a recovery rate of 40% mean if default occurs by maturity?

   (a) A recovery cash flow equal to 40% of par is paid at maturity
   (b) A recovery cash flow equal to 40% of the current market price is paid at maturity
   (c) A recovery cash flow equal to 60% of par is paid at maturity

2. A one-period claim has USD 2,000 par, a current price of USD 1,850, and a 25% recovery-of-par rate. Under the lesson model, which positive recovery cash flow is used after default?

   (a) USD 500 at maturity
   (b) USD 462.50 at maturity
   (c) USD 1,500 at maturity

3. Enter loss given default as a decimal when the recovery rate is 35% (0.35).

4. A recovery-of-par model pays USD 900 after default on a claim with USD 1,500 par. Enter loss given default as a decimal.

5. A one-period defaultable zero-coupon claim has USD 1,000 par, survival probability 0.90 to maturity, recovery-of-par rate 0.40 after default, and maturity discount factor 0.95. Both the survival payoff and any recovery are paid at maturity. What is its time-zero present value in USD?

6. A one-period defaultable zero-coupon claim has USD 2,500 par, cumulative default probability 0.08, loss given default 0.55, and maturity discount factor 0.92. The recovery-of-par amount after default is paid at maturity. What is its time-zero present value in USD?

Answers: end of the chapter.

6.2.6 Model boundary and review note

The model has one maturity date, one deterministic recovery rate, one input survival probability, and one input discount factor. Recovery is a fraction of par paid at maturity, also when default occurs earlier. The lesson omits:

- settlement at the default time;
- coupons and multiple intervals;
- stochastic recovery and recovery of market value;
- dependence between interest rates and default;
- calibration;
- liquidity, funding, taxes, and counterparty risk.

All materially changed content and source locators remain 'draft' pending independent human review.

References

[1] Tuckman & Serrat, Fixed Income Securities: Tools for Today's Markets (4th ed., 2022). Ch. 14 §14.2, printed p. 353.

[2] Shreve, Stochastic Calculus for Finance II: Continuous-Time Models (2004). Ch. 1 §1.3, printed pp. 13–18.

[3] Tuckman & Serrat, Fixed Income Securities: Tools for Today's Markets (4th ed., 2022). Ch. 14 §14.7, printed pp. 371–372, eq. 14.8 and Table 14.11.

Answers to the knowledge checks

Knowledge check 6.2.1: Recovery and risky present value

1. **(a)** A recovery cash flow equal to 40% of par is paid at maturity. Under this narrow model, recovery uses par as its base and is paid at the common maturity date.
2. **(a)** USD 500 at maturity. Recovery is 0.25 × USD 2,000 par = USD 500; the current price is not the recovery base in this model.
3. 0.65 (accepted within $\pm 1e-12$). Loss given default is 1 - recovery rate = 1 - 0.35 = 0.65.
4. 0.4 (accepted within $\pm 1e-12$). The recovery rate is 900 / 1,500 = 0.60, so loss given default is 1 - 0.60 = 0.40.
5. 893 (accepted within ±0.01). The probability-weighted maturity payoff is 1,000 × [0.90 + (1 - 0.90) × 0.40] = 940. Discounting gives 0.95 × 940 = 893.
6. 2198.8 (accepted within ±0.01). The probability-weighted payoff factor is 1 - 0.08 × 0.55 = 0.956. Present value is 2,500 × 0.92 × 0.956 = 2,198.80.

Appendix A

Notation

The symbols of this book, in the order they first appear.

i **Credit period index**. Selects one interval in the lesson's ordered survival schedule. The index is bookkeeping and is not itself a time or probability. *In Chapter 6.1 only.*

$$i \in \{1, \dots, n\}$$

Δt **Credit small time increment**. Positive model-time interval used in the conditional definition of hazard. The hazard definition takes this increment down toward zero while holding the starting time fixed. *Units:* model-years. *In Chapter 6.1 only.*

$$\Delta t > 0$$

n **Number of credit periods**. Counts the intervals in the input survival schedule. It is a positive integer count for this finite toy model. *In Chapter 6.1 only.*

$$n \in \{1, 2, ...\}$$

$A(0,t)$ **Accumulation factor**. Grows one current unit over a stated future horizon under the selected rate model. *Units:* dimensionless currency-units per current currency-unit.

m **Compounding frequency**. Number of equal compounding periods per year under the stated rate convention, a positive integer fixed by the model convention. *Units:* compounding periods per year.

τ **Default time**. Random model time at which the reference entity first defaults. It is measured in model-years from valuation time under the stated risk-neutral model. *Units:* model-years after valuation time.

$$\tau > 0$$

$D(0,t)$ **Discount factor**. Converts one deterministic future unit into value at valuation time. *Units:* current currency-units per future currency-unit.

$\mathbb{E}$ **Expectation**. Operator returning the average of a random quantity, each outcome weighted by its probability under a stated measure; a superscript names that measure when more than one is in play. *Units:* value units.

$$\mathbb{E}[X] = \int_{\Omega} X(\omega)\, d\mathbb{P}(\omega)$$

λ **Constant hazard rate**. Constant conditional default intensity used by the lesson's simplified exponential survival model; a risk-neutral pricing input conditional on survival to the current instant, not a cumulative probability. *Units:* decimal intensity per model-year.

Δq_i **Interval default probability**. Probability assigned by the model to first default during one stated time interval, conditional only through the input survival curve construction. *Units:* probability between zero and one.

$j^{(m)}$ **Nominal annual rate**. Annualized rate quote that must be paired with its compounding frequency. *Units:* decimal rate per year.

t_k **Payment time**. Time from the valuation date to one scheduled cash-flow event; a time coordinate, not a calendar date or payment index. *Units:* years from the valuation date.

r_m **Periodic rate**. Rate applied once in each compounding period under the stated convention, derived from the stated nominal annual quote in this model. *Units:* decimal per compounding period.

$\mathbb{Q}$ **Risk-neutral probability measure**. Gives model pricing weights under which discounted traded prices satisfy the martingale condition; it prices payoffs relative to a stated numeraire and is not a forecast of actual event frequencies. *Units:* dimensionless probability weights between zero and one.

$S(0,t)$ **Survival probability**. Probability, under the explicitly stated model measure, that no modeled default has occurred between valuation time and a stated future time. *Units:* probability between zero and one.

t **Time from valuation**. A time measured in years from the valuation time; a time coordinate, not a calendar date or a schedule index. With a row index it is a payment time. *Units:* years from the valuation date.

0 **Valuation time**. Common origin from which later model times and present values are measured. *Units:* years from the valuation date.

F **Recovery par amount**. Positive currency amount promised after survival and used as the recovery base after default. It is a toy-model input and not a market price. *Units:* stated currency at the scheduled payment time. *In Chapter 6.2 only.*

$$F > 0$$

T **Recovery payment time**. Single future time when either the survival-state or recovered-par amount is paid. Default may occur earlier, but this toy convention delays the recovered-par payment to this time. *Units:* model-years from valuation time. *In Chapter 6.2 only.*

$$T > 0$$

LGD **Loss given default**. Fraction of an explicitly stated reference amount not recovered under a deterministic recovery convention, relative to the same reference amount used by the recovery rate. *Units:* decimal fraction between zero and one.

PV_0 **Present value**. Combines dated signed cash flows into one value at valuation time, using the same holder perspective as the signed cash flows. *Units:* stated currency at the valuation time.

PV_0^{RoP} **Recovery of par present value**. Present value of one maturity payment that is par after survival and a fixed fraction of par after earlier default; a positive asset value to the holder in the one-period recovery-of-par-paid-at-maturity model. *Units:* stated currency at valuation time.

R **Recovery rate**. Fraction of a stated reference amount recovered after a modeled default under an explicitly stated recovery convention; a non-negative fraction whose reference amount, payment timing, and settlement convention are set by the model that uses it. *Units:* decimal fraction between zero and one.

CF_k **Signed cash flow**. Amount received or paid at one event from the stated holder perspective; positive means received and negative means paid by that holder. *Units:* stated currency units.

Appendix B

Abbreviations

CDS Credit default swap, the credit derivative the CDS lessons define and value.

CDX The name of a family of standard credit default swap indices, each a standard portfolio of single-name contracts.

DTS Duration times spread, a spread-risk measure for bonds.

FINRA Financial Industry Regulatory Authority.

IMM International Money Market. In the CDS lessons, IMM dates are the standard maturity dates on the twentieth of March, June, September, and December.

ISDA International Swaps and Derivatives Association.

ISO International Organization for Standardization.

JTD Jump to default, the loss on an immediate default of the reference entity.

UTC Coordinated Universal Time, the time standard the date arithmetic counts calendar days in.