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# **Discounting Revisited. Valuations under Funding Costs, Counterparty Risk and Collateralization.**

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# Discounting Revisited.

## Valuations under Funding Costs, Counterparty Risk and Collateralization.

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### Abstract

Looking at the valuation of a swap when funding costs and counterparty risk are neglected (i.e., when there is a unique risk free discounting curve), it is natural to ask “What is the discounting curve of a swap in the presence of funding costs, counterparty risk and/or collateralization”.

In this note we try to give an answer to this question. The answer depends on who you are and in general it is “There is no such thing as a unique discounting curve (for swaps).” Our approach is somewhat “axiomatic”, i.e., we try to make only very few basic assumptions. We shed some light on use of *own credit risk* in mark-to-market valuations, giving that the mark-to-market value of a portfolio increases when the owner’s credibility decreases.

We presents two different valuations. The first is a mark-to-market valuation which determines the liquidation value of a product. It does, by construction, exclude any funding cost. The second is a portfolio valuation which determines the replication value of a product including funding costs.

We will also consider counterparty risk. If funding costs are presents, i.e., if we value a portfolio by a replication strategy then counterparty risk and funding are tied together:

- In addition to the default risk with respect to our exposure we have to consider the loss of a potential funding benefit, i.e., the impact of default on funding.
- Buying protection against default has to be funded itself and we account for that.

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# 1 Introduction

Looking at the valuation of a swap when funding costs and counterparty risk are neglected (i.e., when there is a unique risk free discounting curve), it is natural to ask “What is the discounting curve of a swap in the presence of funding costs, counterparty risk and/or collateralization”.

The answer depends on who you are and how we value. Factoring in funding costs the answer to that question is “There is no such thing as a unique discounting curve (for swaps).”

## 1.1 Two Different Valuations

In Section 2 we will first take a simplified view in valuing claims and cash flows: We view the market price of a zero coupon bond as the value of a claim and value all claims according to such zero coupon bond prices. However, this is only one point of view. We could call it the third party (mark-to-market) liquidation view which is to ask what is the value of a portfolio of claims if we liquidate it today. This approach does not value funding cost.

In Section 3 we will then construct a different valuation which includes the funding costs of net cash requirements. These funding costs occur over the life time of the product. They are of course not present if the portfolio is liquidated. This alternative valuation will also give an answer to an otherwise puzzling problem: In the mark-to-market valuation it appears that the value of the portfolio increases if its credit rating decreases (because liabilities are written down). However, if we include the funding cost, then the effect is reversed since funding costs are increased, and since we are not liquidating the portfolio we have to factor them in.

The difference of the two valuations is their point of view. Liquidating a portfolio we value it from “outside” as a third party. Accounting for operational cost we value it from the “inside”. The two parties come to different values because of a very simple fact: We cannot short sell our own bond (sell protection on our self). However, a third party can do.

## 2 Discounting Cash Flows: The Third Party (Mark-to-Market) Liquidation View

Let us first take the point of view of being a third party and value claims between to other entities A and B. We lay the foundation of discounting, which is given by considering a single financial product: *the zero coupon bond*. Discounting, i.e., discount factors are given by the price at which a zero coupon bond can be sold or bought. Let us formalize this set up:

### 2.1 Discount Factors for Outgoing and Incoming Cash Flows

Assume entity A can issue a bond with maturity  $T$  and notional 1. By this we mean that A offers the financial product which offers the payment of 1 in time  $T$ . Let us denote the time  $t$  market price of this product by  $P^A(T; t)$ . This is the value at which the market is willing to buy or sell this bond.

Likewise let  $P^B(T; t)$  denote the price at which the market is willing to buy or sell bonds issued by some other entity B.

Assume that A receives a cash flow  $C(T) > 0$  from entity B. This corresponds to A holding a zero coupon bond from entity B having notional  $C(T)$  and maturity  $T$ . Hence, the time  $T$  value of this isolated cash flow is  $C(T)P^B(T; T)$  (seen from A's perspective). Given that  $C(T)$  is not stochastic, the time  $t < T$  value of this isolated cash flow then is  $C(T)P^B(T; t)$ . We will call this cash flow "incoming", however we want to stress that we view ourself as a third party independent of A and B trading in bonds. Thus we have:  $P^B(T; t)$  is the discount factor of all *incoming cash flows* from entity B.

Consider some other contract featuring a cash flow  $C(T) > 0$  from A to B at time  $T$ . The time  $T$  value of this cash flow is  $-C(T)P^A(T; T)$ , where we view the value from A's perspective, hence the minus sign. We will call this cash flow outgoing, however we want to stress again that view ourself as a third party independent of A and B trading in bonds. Given that  $C(T)$  is not stochastic, the time  $t < T$  value of this isolated cash flow then is  $-C(T)P^A(T; t)$ . Thus we have:  $P^A(T; t)$  is the discount factor of all *outgoing cash flows* of entity A.

Since we view ourself as a third party, we have that in this framework the discount factor of a cash flow is determined by the value of the zero coupon bonds of the originating entity.

If we view a cash flow  $|C(T)|$  between A and B from the perspective of the entity A such that  $C(T) > 0$  means that the cash flow is incoming (positive value for A) and  $C(T) < 0$  means that the cash flow is outgoing, then its time  $T$  value can be written as

$$\min(C(T), 0) P^A(T; T) + \max(C(T), 0) P^B(T; T).$$

#### 2.1.1 Valuation of a Fixed Coupon Bond

The knowledge of the discount factors allows the valuation of a fixed coupon bond, because here all future cash flows have the same origin.

## 2.2 Counterparty Risk

The price  $P^A(T; t)$  contains the time-value of a cash flow from **A** (e.g., through a risk free interest rate) and the counterparty risk of **A**.

Usually we expect

$$0 \leq P^A(T; T) \leq 1,$$

and due to **A**'s credit risk we may have  $P^A(T; T, \omega) < 1$  for some path  $\omega$ . As a consequence, we will often use the symbol  $P^A(T; T)$  which would not be present if counterparty risk (and funding) would have been neglected.

In Section 2.6 we will see a case where  $P^{Ac}(T; T, \omega) > 1$  will be meaningful for some "virtual" entity  $A_C$ , namely for over-collateralized cash flows from **A**.

### 2.2.1 Example

If we do not consider "recoveries" then  $P^A(T; T, \omega) \in \{0, 1\}$ . For example, if entity **A** defaults in time  $\tau(\omega)$ , then we have that  $P^A(T; t, \omega) = 0$  for  $t > \tau(\omega)$ .

## 2.3 Netting

Let us now consider that entity **A** and **B** have two contracts with each other: one resulting in a cash flow from **A** to **B**. The other resulting in a cash flow from **B** to **A**. Let us assume further that both cash flow will occur at the same future time  $T$ . Let  $C^A(T) > 0$  denote the cash flow originating from **A** to **B**. Let  $C^B(T) > 0$  denote the cash flow originating from **B** to **A**. Individually the time  $T$  value of the two contracts is

$$-C^A(T) P^A(T; T) \quad \text{and} \quad +C^B(T) P^B(T; T),$$

where the signs stem from considering the value from **A**'s perspective. From **B**'s perspective we would have the opposite signs. If  $C^A(T)$  and  $C^B(T)$  are deterministic, then the time  $t$  value of these cash flows is

$$-C^A(T) P^A(T; t) \quad \text{and} \quad +C^B(T) P^B(T; t),$$

respectively.

However, if we have a netting agreement, i.e., the two counter parties **A** and **B** agree that only the net cash flow is exchanged, then we effectively have a single contract with a single cash flow of

$$C(T) := -C^A(T) + C^B(T).$$

The origin of this cash flow is now determined by its sign. If  $C(T) < 0$  then  $|C(T)|$  flows from **A** to **B**. If  $C(T) > 0$  then  $|C(T)|$  flows from **B** to **A**. The time  $T$  value of the netted cash flow  $C(T)$ , seen from **A**'s perspective, is

$$\min(C(T), 0) P^A(T; T) + \max(C(T), 0) P^B(T; T).$$

Note that if

$$P^A(T; t) = P^B(T; t) =: P(T; t)$$

then there is no difference between the value of a netted cash flow and the sum the individual values, but in general this property does not hold.

## 2.4 Valuation of Stochastic Cash Flows

If cash flows  $C(T)$  are stochastic, then we have to value their time  $t$  value using a valuation model, e.g., risk neutral valuation using some numeraire  $N$  and a corresponding martingale measure  $\mathbb{Q}^N$ . The analytic valuation (which actually stems from a static hedge) as  $C(T)P^A(T; t)$  no longer holds. Let  $N$  denote a numeraire and  $\mathbb{Q}^N$  a corresponding martingale measure, such that,

$$\frac{P^A(T; t)}{N(t)} = \mathbb{E}^{\mathbb{Q}^N} \left( \frac{P^A(T; T)}{N(T)} \mid \mathcal{F}_t \right).$$

Then a possibly stochastic cash flow  $C(T)$ , outgoing from **A** is evaluated in the usual way, where the value is given as

$$\mathbb{E}^{\mathbb{Q}^N} \left( \frac{C(T) P^A(T; T)}{N(T)} \mid \mathcal{F}_t \right)$$

Note that the factor  $P^A(T; T)$  determines the effect of the origin of the cash flow, here **A**. In theories where counterparty risk (and funding) is neglected, the cash flow  $C(T)$  is valued as

$$\mathbb{E}^{\mathbb{Q}^N} \left( \frac{C(T)}{N(T)} \mid \mathcal{F}_t \right).$$

## 2.5 Credit Linking

Let us consider a bond  $P^C(T; t)$  issued by entity **C**. Let us consider a contract where **A** pays  $P^C(T; T)$  in  $t = T$ , i.e., **A** pays 1 only if **C** survived, otherwise it will pay **C**'s recovery. However, this cash flow still is a cash flow originating (granted) by **A**. The time  $T$  value of this cash flow is  $P^C(T; T)P^A(T; T)$ .

This contract can be seen as a credit linked deal.

### 2.5.1 Examples

If  $P^C(T; T, \omega) = 1$  for all  $\omega \in \Omega$ , then  $P^C$  has no credit risk. In this case we have

$$N(t)\mathbb{E}^{\mathbb{Q}^N} \left( \frac{P^C(T; T)P^A(T; T)}{N(T)} \mid \mathcal{F}_t \right) = P^A(T; t).$$

Also, if  $P^C(T; T, \omega) = P^A(T; T, \omega) \in \{0, 1\}$  for all  $\omega \in \Omega$ , then **C** defaults if and only if **A** defaults and there are no recoveries. In that case we also have

$$N(t)\mathbb{E}^{\mathbb{Q}^N} \left( \frac{P^C(T; T)P^A(T; T)}{N(T)} \mid \mathcal{F}_t \right) = P^A(T; t).$$

If the two random variables  $P^A(T; T)$  and  $P^C(T; T)$  are independent we have

$$N(t)\mathbb{E}^{\mathbb{Q}^N} \left( \frac{P^C(T; T)P^A(T; T)}{N(T)} \mid \mathcal{F}_t \right) = P^C(T; t) P^A(T; t) \frac{1}{P(T; t)},$$

where  $P(T; t) := N(t)\mathbb{E}^{\mathbb{Q}^N} \left( \frac{1}{N(T)} \mid \mathcal{F}_t \right)$ .



To prove the latter we switch to terminal measure (i.e., choose  $N = P(T)$  such that  $N(T) = 1$ ) and get

$$\begin{aligned} & N(t) \mathbb{E}^{\mathbb{Q}^N} \left( \frac{P^C(T; T) P^A(T; T)}{N(T)} \mid \mathcal{F}_t \right) \\ &= N(t) \mathbb{E}^{\mathbb{Q}^N} \left( P^C(T; T) \mid \mathcal{F}_t \right) \mathbb{E}^{\mathbb{Q}^N} \left( P^A(T; T) \mid \mathcal{F}_t \right) \\ &= P^C(T; t) P^A(T; t) \frac{1}{N(t)} = P^C(T; t) P^A(T; t) \frac{1}{P(T; t)} \end{aligned}$$

## 2.6 Collateralization

Collateralization is not some “special case” which has to be considered in the above valuation framework. Collateralization is an additional contract with an additional netting agreement (and a credit link). As we will illustrate, we can re-interpret a collateralized contract as a contract with a different discount curve, however, this *is* only a re-interpretation.

For simplicity let us consider the collateralization of a single future cash flow.

Let us assume that counterparty **A** pays  $M$  in time  $T = 1$ . Thus, seen from the perspective of **A**, there is a cash flow

$$-MP^A(T; T) \quad \text{in } t = T.$$

Hence, the time  $t$  value of the non-collateralized cash flow is  $-MP^A(T; t)$ . Next, assume that counterparty **A** holds a contract where an entity **C** will pay  $K$  in time  $T$ . Thus, seen from the the perspective of **A** there is a cash flow

$$KP^C(T; T) \quad \text{in } t = T.$$

Hence, the time  $t$  value of this cash flow is  $KP^C(T; t)$ .

If we value both contracts separately, then the first contract evaluates to  $-N$ , the second contract evaluates to  $K$ . If we use the second contract to “collateralize” the first contract we bundle the two contracts in the sense that the second contract is passed to the counterparty **B** as a pawn. This can be seen as letting the second contract default if the first contract defaults. The time  $T$  value thus is

$$\left( KP^C(T; T) - M \right) P^A(T; T),$$

where we assumed that the net cash flow is non-positive, which is the case if  $K < M$  and  $P^C(T; T) \leq 1$ , so we do not consider over-collateralization. The random variable  $P^C(T; T)$  accounts for the fact that the collateral may itself default over the time, see “credit linked” above.

We have

$$\begin{aligned} & \left( KP^C(T; T) - M \right) P^A(T; T) \\ &= KP^C(T; T) - MP^A(T; T) + K \left( P^C(T; T) P^A(T; T) - P^C(T; T) \right) \end{aligned}$$

Thus, the difference of the value of the collateralized package and the sum of the individual deals ( $M - K$ ) is

$$K \left( P^C(T; T)P^A(T; T) - P^C(T; T) \right).$$

It is possible to view this change of the value of the portfolio as a change of the value of the outgoing cash flow. Let us determine the implied zero coupon bond process  $P^{Ac}$  such that

$$\begin{aligned} -M P^{Ac}(T; T) &\stackrel{!}{=} -M P^A(T; T) \\ &\quad + K \left( P^C(T; T)P^A(T; T) - P^C(T; T) \right). \end{aligned}$$

It is

$$P^{Ac}(T; T) := P^A(T; T) - \frac{K}{M} \left( P^C(T; T)P^A(T; T) - P^C(T; T) \right). \quad (1)$$

We refer to  $P^{Ac}$  as the discount factor for collateralized deals. It should be noted that a corresponding zero coupon bond does not exist (though it may be synthesized) and that this discount factor is simply a computational tool. In addition, note that the discount factor depends on the value ( $K$ ) and quality ( $P^C(T; T)$ ) of the collateral.

### 2.6.1 Interpretation

From the above, we can check some limit cases:

- For  $P^C(T; T)P^A(T; T) = P^C(T; T)$  we find that  $P^{Ac}(T; T) = P^A(T; T)$ . Note that this equations holds, for example, if  $P^A(T; T) < 1 \Rightarrow P^C(T; T)$ . This can be interpreted as: if the quality of the collateral is “less or equal” to the quality of the original counterpart, then collateralization has no effect.
- For  $P^C(T; T)P^A(T; T) = P^A(T; T)$  and  $0 \leq K \leq M$  we find that  $P^{Ac}(T; T) = \alpha P^C(T; T) + (1 - \alpha)P^A(T; T)$ , where  $\alpha = \frac{K}{M}$ , i.e., if the collateral does not compromise the quality of the bond as a credit linked bond, then collateralization constitutes a mixing of the two discount factors at the ratio of the collateralized amount.
- For  $P^C(T; T)P^A(T; T) = P^A(T; T)$  and  $K = M$  we find that  $P^{Ac}(T; T) = P^C(T; T)$ , i.e., if the collateral does not compromise the quality of the bond as a credit linked bond and the collateral matches the future cash flow, then the collateralized discount factor agrees with the discount factor of the collateral.

Given that  $P^C(T; T)P^A(T; T) = P^A(T; T)$  we find that collateralization has a positive value for the entity receiving the collateral. The reason can be interpreted in a funding sense: The interest payed on the collateral is less than the interest payed on an issued bond. Hence, the entity receiving collateral can save funding costs.

### 2.6.2 Example

Let us consider entities **A** and **C** where

$$N(t) E^{\mathbb{Q}^N} \left( \frac{P^A(T; T)}{N(T)} | \mathcal{F}_t \right) = \exp(-r(T-t)) \exp(-\lambda^A(T-t))$$

$$N(t) E^{\mathbb{Q}^N} \left( \frac{P^C(T; T)}{N(T)} | \mathcal{F}_t \right) = \exp(-r(T-t)) \exp(-\lambda^C(T-t))$$

and

$$N(t) E^{\mathbb{Q}^N} \left( \frac{P^C(T; T) P^A(T; T)}{N(T)} | \mathcal{F}_t \right) \\ = \exp(-r(T-t)) \exp(-\lambda^C(T-t)) \exp(-\lambda^A(T-t)).$$

The first two equations could be viewed as a definition of some base interest rate level  $r$  and the counterparty dependent default intensities  $\lambda$ . So to some extent these equations are definitions and do not constitute an assumption. However, given that the base level  $r$  is given, the third equation constitutes an assumption, namely that the defaults of **A** and **C** are independent.

From this we get for the impact of collateralization that

$$P^{Ac}(T; t) = \exp(-r(T-t)) \exp(-\lambda^A(T-t)) \cdot \left( 1 + \frac{K}{M} \exp(-\lambda^C(T-t)) \left( \exp(\lambda^A(T-t)) - 1 \right) \right).$$

Note that for  $K > M$  this discount factor could have  $P^{Ac}(T; T) > 1$ . This would correspond to the case where the original deal is over-collateralized. We excluded this case in the derivation and in fact the formula above does not hold in general for an over-collateralized deal, since we would need to consider the discount factor of the counterpart receiving the collateral (the over-collateralized part is at risk now). Nevertheless, a similar formula can be derived.

### 2.6.3 Full Bilateral Collateralization

Full bilateral collateralization with collateral having the same discount factor, i.e.,  $P^{Ac}(T) = P^{Bd}(T)$ , will result in a single discounting curve (namely that of the collateral) regardless of the origin of the cash flow.

### 3 Discounting Cash Flows: The Hedging View

We now take a different approach in valuing cash flows and we change our point of view. We now assume that *we are* entity **A** and as a consequence postulate that

**Axiom 1: (Going Concern)**

*Entity A wants to stay in business (i.e., liquidation is not an option) and cash flows have to be “hedged” (i.e., neutralized, replicated). In order to stay in business, future outgoing cash flows have to be ensured.*

The axiom means that we do not value cash flows by relating them to market bond prices (the liquidation view). Instead we value future cash flows by trading in assets such that future cash flows are hedged (neutralized). The costs or proceeds of this trading define the value of future cash flows. An entity must do this because all uncovered negative net cash flow will mean default. Future net (!) cash flow is undesirable. A future cash flow has to be managed.

This is to some extent reasonable since cash itself is a bad thing. It does not earn interest. It needs to be invested. We will take a replication / hedging approach to value future cash. In addition we take a conservative point of view: a liability in the future (which cannot be neutralized by trading in some other asset (netting)) has to be secured in order to ensure that we stay in business. Not paying is not an option. This relates to the “going concern” as a fundamental principle in accounting.

At this point one may argue that a future outgoing cash flow is not a problem. Once the cash has to flow we just sell an asset. However, then we would be exposed to risk in that asset. This is not the business model of a bank. A bank hedges its risk and so future cash flow has to be hedged as well. Valuation is done by valuing hedging cost.

Changing the point of view, i.e., assuming that *we are* entity **A** has another consequence, which we also label as an “Axiom”:

**Axiom 2:**

*We cannot short sell our own bond*

The rationale of this is clear: While a third party **E** actually can short sell a bond issued by **A** by selling protection on **A**, **A** itself cannot offer such an instrument. It would offer an insurance on its own default, but if the default occurs, the insurance does not cover the event. Hence the product is worthless.

#### 3.1 Moving Cash Flow through Time

Axiom 1 requires that we consider transactions such that all future cash flow is converted into today's cash flow, where then a netting of cash occurred and remaining cash can be invested into assets (or business) generating interest. Axiom 2 then restricts the means how we can move cash flows around.

Let us explore the means of “moving” cash through time. To illustrate the concept we first consider deterministic cash flows only. These allow for static hedges through the construction of appropriate forward bonds in Section 3.2.

Let us assume that there is a risk free entity issuing risk free Bonds  $P^\circ(T; t)$  by which we may deposit cash.<sup>1</sup>

### 3.1.1 Moving Positive Cash to the Future

If entity A (i.e., *we*) has cash  $N$  in time  $t$  it can invest it and buy bonds  $P^\circ(T; t)$ . The cash flow received in  $T$  then is  $N \frac{1}{P^\circ(T; t)}$ .

This is the way by which positive cash can be moved from  $t$  to a later time  $T > t$  (risk less, i.e., suitable for hedging). Note that investing in to a bond  $P^B(T; t)$  of some other entity B is not admissible since then the future cash flow would be credit linked to B.

### 3.1.2 Moving Negative Cash to the Future

If entity A (i.e., *we*) has cash  $-N$  in time  $t$  it has to issue a bond in order to cover this cash. In fact, there is no such thing as negative cash. Either we have to sell assets or issue a bond. Assume for now that selling assets is not an option. Issuing a bond generating cash flow  $+N$  (proceeds) the cash flow in  $T$  then is  $-N \frac{1}{P^A(T; t)}$  (payment).

This is the way by which negative cash can be moved from  $t$  to a later time  $T > t$ .

### 3.1.3 Hedging Negative Future Cash Flow

If entity A (i.e., *we*) is confronted with a cash flow  $-N$  in time  $T$  it needs to hedge (guarantee) this cash flow by depositing  $-N \frac{1}{P^\circ(T; t)}$  today (in bonds  $P^\circ(T; t)$ ).

This is the way by which negative cash can be moved from  $T$  to an earlier time  $t < T$ .

A remark is in order now: An alternative to net a future outgoing cash flow is by buying back a corresponding  $-P^A(T; t)$  bond. However, let us assume that buying back bonds is currently not an option, e.g., for example because there are no such bonds. Note that due to Axiom 2 it is not admissible to short sell our own bond.<sup>2</sup>

### 3.1.4 Hedging Positive Future Cash Flow

If entity A (i.e., *we*) is confronted with a cash flow  $+N$  in time  $T$  it needs to hedge (net) this cash flow by issuing a bond with proceeds  $N \frac{1}{P^A(T; t)}$  today (in bonds  $P^\circ(T; t)$ ).

This is the way by which positive cash can be moved from  $T$  to an earlier time  $t < T$ .

## 3.2 Construction of Forward Bonds

The basic instrument to manage cash flows will be the forward bond transaction, which we consider next. To comply with Axiom 2 we simply assume that we can only enter in one of the following transactions, never sell it. Hence we have to consider two different forward bonds.

<sup>1</sup> Counterparty risk will be considered at a later stage.

<sup>2</sup> We will later relax this assumption and allow for (partial) funding benefits by buying back bonds.

### 3.2.1 Forward Bond 1: Hedging Future Incoming Cash with Outgoing Cash

Assume we have an incoming cash flow  $M$  from some counterparty risk free entity to entity **A** in time  $T_2$  and an outgoing cash flow  $-N$  from entity **A** (i.e., *we*) to some other entity in time  $T_1$ . Then we perform the following transactions

- We neutralize (secure) the outgoing cash flow by an incoming cash flow  $N$  by investing  $-NP^\circ(T_1; 0)$  in time 0.
- We net the incoming cash flow by issuing a bond in  $t = 0$  paying back  $-M$ , where we securitize the issued bond by the investment in  $NP^\circ(T_1; 0)$ , resulting in  $MP^A(T_2; 0) \frac{P^\circ(T_1; 0)}{P^A(T_1; 0)}$ . Note that the issued bond is securitized only over the period  $[0, T_1]$ .

This transaction has zero costs if  $N = M \frac{P^A(T_2; 0)}{P^A(T_1; 0)}$ . Let

$$P^A(T_1, T_2) := \frac{P^A(T_2)}{P^A(T_1)}.$$

### 3.2.2 Forward Bond 2: Hedging Future Outgoing Cash with Incoming Cash

Assume we have an outgoing cash flow  $-M$  in  $T_2$  and an incoming cash flow  $N$  from some counterparty risk free entity to entity **A** (i.e., *us*) in  $T_1$ . Then we perform the following transactions

- We neutralize (secure) the outgoing cash flow by an incoming cash flow  $N$  by investing  $-NP^\circ(T_2; 0)$  in time  $t = 0$ .
- We net the incoming cash flow by issuing a bond in  $t = 0$  paying back  $-M$ , where we securitize the issued bond by the investment in  $NP^\circ(T_2; 0)$ , resulting in  $MP^\circ(T_1; 0)$ .

This transaction has zero costs if  $N = M \frac{P^\circ(T_2; 0)}{P^\circ(T_1; 0)}$ . Let

$$P^\circ(T_1, T_2) := \frac{P^\circ(T_2)}{P^\circ(T_1)}.$$

### 3.2.3 Forward Bond 1': Hedging Future Credit Linked Incoming Cash with Credit Linked Outgoing Cash

In the presence of counterparty risk, the construction of the forward bond (discounting of an incoming cash flow) is a bit more complex. Assume we have an incoming cash flow  $M$  from entity **B** to entity **A** in time  $T_2$ . We assume that we can buy protection on  $M$  received from **B** at  $-CDS^B(T_2; t)$ , where this protection fee is paid in  $T_2$ . Assume further that we can sell protection on  $N$  received from **B** at  $CDS^B(T_1; t)$ , where this protection fee is paid in  $T_1$ . Then we repeat the construction of the forward bond with the net protected amounts  $M(1 - CDS^B(T_2; t))$  and  $N(1 - CDS^B(T_1; t))$ , replacing  $M$  and  $N$  in 3.2.1 respectively. In other words we perform the following transactions

- We buy protection on **B** resulting in a cash flow  $-MCDS^B(T_2; t)$  in  $T_2$ .

- We issue a bond to net the  $T_2$  net cash flow  $M(1 - \text{CDS}^{\text{B}}(T_2; t))$ .
- We sell protection on  $\mathbf{B}$  resulting in a cash flow  $N\text{CDS}^{\text{B}}(T_1; t)$  in  $T_1$ .
- We invest  $N(1 - \text{CDS}^{\text{B}}(T_1; t))P^{\circ}(T_1; 0)$  in  $t$  to generate a cash flow of  $N(1 - \text{CDS}^{\text{B}}(T_1; t))$  in  $T_1$ .
- We collateralized the issued bond using the risk free bond over  $[0, T_1]$  resulting in proceeds  $M(1 - \text{CDS}^{\text{B}}(T_2; t))P^{\text{A}}(T_2; 0)\frac{P^{\circ}(T_1; 0)}{P^{\text{A}}(T_1; 0)}$  in  $t$ .

This transaction has zero costs if  $N = M\frac{P^{\text{A}}(T_2; 0)}{P^{\text{A}}(T_1; 0)}\frac{1 - \text{CDS}^{\text{B}}(T_2; t)}{1 - \text{CDS}^{\text{B}}(T_1; t)}$ . Let

$$P^{\text{A}|\text{B}}(T_1, T_2) := \frac{P^{\text{A}}(T_2)}{P^{\text{A}}(T_1)} \frac{1 - \text{CDS}^{\text{B}}(T_2; t)}{1 - \text{CDS}^{\text{B}}(T_1; t)}.$$

However, while this construction will give us a cash flow in  $T_1$  which is (because of selling protection) under counterparty risk, netting of such a cash flow will require more care. We will consider this in Section 3.4, there we apply this construction with  $t = T_1$  such that selling protection does not apply.

### 3.2.4 Price of Counterparty Risk Protection

We denote the price of one unit of counterparty risk protection until  $T_2$  as contracted in  $t$  by  $\text{CDS}^{\text{B}}(T_2; t)$  since we do not consider liquidity effects a fair (mark-to-marked) valuation will give

$$P^{\text{B}}(T_2; t) + \text{CDS}^{\text{B}}(T_2; t)P^{\circ}(T_2; t) = P^{\circ}(T_2; t),$$

where we assume that the protection fee flows in  $T_2$  (and independently of the default event). This gives

$$1 - \text{CDS}^{\text{B}}(T_2; t) = \frac{P^{\text{B}}(T_2; t)}{P^{\circ}(T_2; t)}.$$

The latter can be interpreted as as a market implied survival probability.

### 3.2.5 Example: Expressing the Forward Bond in Terms of Rates

If we define

$$\begin{aligned} \frac{P^{\circ}(T_2; t)}{P^{\circ}(T_1; t)} &= \exp\left(-\int_{T_1}^{T_2} r(\tau; t) d\tau\right) \\ \frac{P^{\text{A}}(T_2; t)}{P^{\text{A}}(T_1; t)} &= \exp\left(-\int_{T_1}^{T_2} r(\tau; t) + s^{\text{A}}(\tau; t) d\tau\right) \\ \frac{1 - \text{CDS}^{\text{B}}(T_2; t)}{1 - \text{CDS}^{\text{B}}(T_1; t)} &= \exp\left(-\int_{T_1}^{T_2} \lambda^{\text{B}}(\tau; t) d\tau\right) \end{aligned}$$

then we have

$$P^{A|B}(T_1, T_2) = \exp\left(-\int_{T_1}^{T_2} r(\tau; t) + s^A(\tau; t) + \lambda^B(\tau; t) d\tau\right)$$

and we see that discounting an outgoing cash flow backward in time by buying the corresponding forward bonds generates additional costs of  $\exp\left(-\int_{T_1}^{T_2} s^A(\tau; t) d\tau\right)$  (funding) compared to discounting an incoming cash flow. In addition incoming cash flows carry the counterparty risk by the additional discounting (cost of protection) at  $\exp\left(-\int_{T_1}^{T_2} \lambda^B(\tau; t) d\tau\right)$ .

### 3.2.6 Interpretation: Funding Cost as Hedging Costs in Cash Flow Management

From the above, we see that moving cash flows around generates costs and the *cash flow replication value* of future cash flows will be lower than the *portfolio liquidation value* of future cash flow. The difference of the two corresponds to the “operating costs of managing un-netted cash flows”, which are just the funding costs. Clearly, liquidating there are no operating cost (so we save them). However these costs are real. If we have cash lying around we can invest only at a risk free rate, however we fund ourself at a higher rate. The only way to reduce cash cost is to net them with other cash flows (e.g. of assets generating higher returns).

## 3.3 Valuation with Hedging Costs in Cash flow Management (Funding)

The cash flow replication value is now given by the optimal combination of forward bonds to hedge (replicate) the future cash flow, where nearby cash flows are “netted” as good a possible. This is given by a backward algorithm, discounting each cash flow according to the appropriate forward bond and then netting the result with the next cash flow.

Let us first consider the valuation neglecting counter party risk, or, put differently, all future cash flows exposed to counter party risk have been insured by buying the corresponding protection first (and reducing net the cash flow accordingly). We will detail the inclusion of counterparty risk in Section 3.4.

### 3.3.1 Interest for Borrowing and Lending

Obviously, using our two assumptions (Axiom 1 and Axiom 2) we arrived at a very natural situation. The interest to be paid for borrowing money over a period  $[T_1, T_2]$  is (as seen in  $t$ )

$$\frac{1}{T_2 - T_1} \left( \frac{P^A(T_1; t)}{P^A(T_2; t)} - 1 \right),$$

i.e., our funding rate. The interest earned by depositing money (risk free) over a period  $[T_1, T_2]$  is

$$\frac{1}{T_2 - T_1} \left( \frac{P^o(T_1; t)}{P^o(T_2; t)} - 1 \right),$$



i.e., the risk free rate. Hence we are in a setup where interest for borrowing and lending are different. The valuation theory in setups when rates for lending and borrowing are different well understood, see for example [3].

### 3.3.2 From Static to Dynamic Hedging

The forward bonds, e.g.,  $P^\circ(T_1, T_2; t)$  or  $P^A(T_1, T_2; t)$  define a static hedge in the sense that their value is known in  $t$ . If we are discounting / hedging stochastic cash flows  $C(T)$  a dynamic hedge is required and  $C(T_i)P^A(T_{i-1}, T_i; T_{i-1})$  is replaced by

$$N(T_{i-1}) \mathbb{E}^{\mathbb{Q}^N} \left( \frac{C(T_i)P^A(T_i; T_i)}{N(T_i)} \right).$$

Note: It is

$$P^A(T_{i-1}, T_i; T_{i-1}) = P^A(T_i; T_{i-1}) = N(T_{i-1}) \mathbb{E}^{\mathbb{Q}^N} \left( \frac{P^A(T_i; T_i)}{N(T_i)} \right),$$

i.e., for  $t = S$  the forward bond  $P(S, T; t)$  is just a bond.

#### Example: Implementation using Euler simulation of Spreads and Intensities

If we express the bonds in terms of the risk free bond  $P^\circ$ , e.g.,

$$\frac{P^A(T_i; t)}{P^\circ(T_i; t)} =: \exp \left( - \int_{T_{i-1}}^{T_i} s^A(\tau; t) d\tau \right)$$

and model (!) the process on the right hand side such that  $s^A(\tau; t)$  is  $\mathcal{F}_{T_{i-1}}$ -measurable for  $t \in [T_{i-1}, T_i]$  (which is usually case if we employ a numerical scheme like the Euler scheme for the simulation of spreads  $s$  and default intensities  $\lambda$ ), then we find that for any cash flow  $C(T_i)$

$$\begin{aligned} & N(T_{i-1}) \mathbb{E}^{\mathbb{Q}^N} \left( \frac{C(T_i)P^A(T_i; T_i)}{N(T_i)} \right) \\ &= N(T_{i-1}) \mathbb{E}^{\mathbb{Q}^N} \left( \frac{C(T_i)}{N(T_i)} \right) \exp \left( - \int_{T_{i-1}}^{T_i} s^A(\tau; t) d\tau \right) P^A(T_{i-1}; T_{i-1}) \end{aligned}$$

and likewise for  $P^B$ .

### 3.3.3 Valuation of a Single Product including Cash Flow Costs

Let us consider the valuation of a collateralized swap being the only product held by entity A. Let us assume the swap is collateralized by cash. The package consisting of the swap's (collateralized) cash flows and the collateral flows has a mark-to-market value of zero (valued according to Section 2), by definition of the collateral. However, the package represents a continuous flow of cash (margining). If valued using the collateral curve  $P^C = P^\circ$  these marginal collateral cash flows have mark-to-market value zero (by definition of the collateral).

Let us assume that this swap constitutes the only product of entity A and that we value cash flows by a hedging approach, i.e., dynamically using the two forward bonds from Section 3.2. Taking into account that for cash we have different interest for borrowing and lending, the collateral cash flow will generate additional costs. These are given by the following recursive definition:

$$\frac{V_i^d(T_{i-1})}{N(T_{i-1})} = E^{\mathbb{Q}^N} \left( \frac{\max(X_i + V_{i+1}^d(T_i), 0)}{N(T_i)} P^A(T_i; T_i) + \frac{\min(X_i + V_{i+1}^d(T_i), 0)}{N(T_i)} P^\circ(T_i; T_i) \mid \mathcal{F}_{T_{i-1}} \right). \quad (2)$$

Here  $V_{i+1}^d(T_i)$  is the net cash position required in  $T_i$  to finance (e.g., fund) the future cash flows in  $t > T_i$ .  $X_i$  is the collateral margin call occurring in time  $t = T_i$ . Hence we have to borrow or lend the net amount

$$V_i^d(T_i) = X_i + V_{i+1}^d(T_i)$$

over the period  $(T_{i-1}, T_i]$ . This amount is then transferred to  $T_{i-1}$  using the appropriate forward bond (discounting) for netting with the next margining cash flow  $X_{i-1}$ .

This is the valuation under the assumption that the  $X_i$  is the *net cash flow* of entity A, e.g., as if the collateralized swap is our only product.

### 3.3.4 Valuation within a Portfolio Context - Valuing Funding Benefits

The situation of Section 3.3.3 now carries over to the valuation of a portfolio of products hold by entity A. In this the algorithm (2) will determine the discount factor to be used in the period  $[T_{i-1}, T_i]$  from the portfolios net cash position  $V_i^d(T_i)$ , regardless of a product having an outgoing or incoming cash flow.

Let us discuss a product having a cash flow  $C(T_i)$  in  $T_i$  being part of entity A's portfolio resulting in a net (cash) position  $V_i^d(T_i)$ .

#### Incoming Cash Flow, Positive Net Position

Given that our net position  $V_i^d(T_i)$  is positive in  $T_i$ , an incoming (positive) cash flow  $C(T_i)$  can be factored in at earlier time only by issuing a bond. Hence it is discounted with  $P^A$  (resulting in a smaller value at  $t < T_i$ , compared to a discounting with  $P^\circ$ ). Note that for  $t > T_i$  this cash flow can provide a funding benefit for a future negative cash flow which would be considered in the case of a negative net position, see 3.3.4).

#### Outgoing Cash Flow, Positive Net Position

Given that our net position  $V_i^d(T_i)$  is positive in  $T_i$ , an outgoing (negative) cash flow  $C(T_i)$  can be served from the positive (net) cash position. Hence it does not require funding for  $t < T_i$  as long as our net cash position is positive. Factoring in the funding benefit it is discounted with  $P^A$  (resulting in a larger value at  $t < T_i$ , compared to a discounting with  $P^\circ$ ).

### Incoming Cash Flow, Negative Net Position

Given that our net position  $V_i^d(T_i)$  is negative in  $T_i$ , an incoming (positive) cash flow  $C(T_i)$  reduces the funding cost for the net position. Hence it represents a funding benefit and is discounted with  $P^\circ$  (resulting in a larger value at  $t < T_i$ , compared to a discounting with  $P^A$ ).

### Outgoing Cash Flow, Negative Net Position

Given that our net position  $V_i^d(T_i)$  is negative in  $T_i$ , an outgoing (negative) cash flow  $C(T_i)$  has to be funded on its own (as long as our net position remains negative). Hence it is discounted with  $P^\circ$  (resulting in a smaller value at  $t < T_i$ , compared to a discounting with  $P^A$ ).

## 3.4 Valuation with Counterparty Risk and Funding Cost

So far Section 3 did not consider counterparty risk in incoming cash flow. Of course, it can be included using the forward bond which includes the cost of protection of a corresponding cash flow.

### 3.4.1 Counterparty Risk in the Absence of Netting

Assume that all incoming cash flows from entity **B** are subject to counterparty risk (default), but all outgoing cash flow to entity **B** have to be served. This would be the case if we consider a portfolio of (zero) bonds only and there is no netting agreement.

Since there is no netting agreement we need to buy protection on each individual cash flow obtained from **B**. It is not admissible to use the forward bond  $P^{A|B}(T_1, T_2)$  to net a  $T_2$  incoming cash flow for which we have protection over  $[T_1, T_2]$  with a  $T_1$  outgoing (to **B**) cash flow and then buy protection only on the net amount.

If we assume, for simplicity, that all cash flows  $X_{i,k}^{B_j}$  received in  $T_i$  from some entity  $B_j$  are known in  $T_0$ , i.e.,  $\mathcal{F}_{T_0}$ -measurable, then we can attribute for the required protection fee in  $T_0$  (i.e., we have a static hedge against counterparty risk) and our valuation algorithm becomes

$$\begin{aligned} \frac{V_i^d(T_{i-1})}{N(T_{i-1})} &= E^{\mathbb{Q}^N} \left( \frac{\max(X_i + V_{i+1}^d(T_i), 0)}{N(T_i)} P^A(T_i; T_i) \right. \\ &\quad \left. + \frac{\min(X_i + V_{i+1}^d(T_i), 0)}{N(T_i)} P^\circ(T_i; T_i) \mid \mathcal{F}_{T_{i-1}} \right). \end{aligned} \quad (3)$$

where the time  $T_i$  net cash flow  $X_i$  is given as

$$X_i := X_i^\circ + \sum_j \sum_k \left( \min(X_{i,k}^{B_j}, 0) + (1 - \text{CDS}^{B_j}(T_i; T_0)) \max(X_{i,k}^{B_j}, 0) \right).$$

where  $B_j$  denote different counterparties and  $X_{i,k}^{B_j}$  is the  $k$ -th cash flow (outgoing or incoming) between us and  $B_j$  at time  $T_i$ . So obviously we are attributing full protection costs for all incoming cash flows and consider serving all outgoing cash flow a must.

Note again, that in any cash flow  $X_{i,k}^{B_j}$  we account for the full protection cost from  $T_0$  to  $T_i$ .

Although this is only a special case we already see that counterparty risk cannot be separated from funding since (3) makes clear that we have to attribute funding cost for the protection fees.<sup>3</sup>

### 3.4.2 Counterparty Risk in the Presence of Netting

However, many contracts feature netting agreements which result in a “temporal netting” for cash flows exchanged between two counterparts and only the net cash flow carries the counterparty risk. It appears as if we could then use the forward bond  $P^{A|B}(T_{i-1}, T_i)$  and  $P^B(T_{i-1}, T_i)$  on our future  $T_i$  net cash flow and then net this one with all  $T_{i-1}$  cash flows, i.e., apply an additional discounting to each netted set of cash flows between two counterparts. This is not exactly right. Presently we are netting  $T_i$  cash flows with  $T_{i-1}$  cash flows in a specific way which attributes for our own funding costs. The netting agreement between two counterparties may (and will) be different from our funding adjusted netting. For example, it the contract may specify that upon default the close out of a product (i.e., the outstanding claim) is determined using the risk free curve for discounting.

Let us denote by  $V_{\text{CLSOUT},i}^B(T_i)$  the time  $T_i$  cash being exchanged / being at risk at  $T_i$  if counterparty **B** defaults according to all netting agreements (the deals close out). This value is usually a part of the contract / netting agreement. Usually it will be a mark-to-market valuation of  $V^B$  at  $T_i$ . One approach to account for the mismatch is to buy protection over  $[T_{i-1}, T_i]$  for the positive part of  $V_{\text{CLSOUT},i}^B(T_i)$  (i.e., the exposure), then additionally buy protection for the mismatch of the contracted default value  $V_{\text{CLSOUT},i}^B(T_i)$  and netted non-default value  $V_i^B(T_i)$ .

As before let  $X_{i,k}^{B_j}$  denote the  $k$ -th cash flow (outgoing or incoming) exchanged between us and entity  $B_j$  at time  $T_i$ . Let

$$R_i^{B_j}(T_i) := \sum_k X_{i,k}^{B_j} + V_{i+1}^{B_j}(T_i)$$

denote the cash value contracted with  $B_j$ , valued (with funding) in  $T_i$ . Then

$$\begin{aligned} V_i^{B_j}(T_i) := & R_i^{B_j}(T_i) - \underbrace{p_j \max(R_i^{B_j}(T_i), 0)}_{\text{protection on netted value including our funding}} \\ & + p_j \underbrace{\left( \min(V_{\text{CLSOUT},i}^{B_j}(T_i), 0) - \min(R_i^{B_j}(T_i), 0) \right)}_{\text{mismatch of liability in case of default}} \end{aligned}$$

is the net value including protection fees over the period  $[T_{i-1}, T_i]$ , where  $p_j$  is the price of buying or selling one unit of protection against  $B_j$  over the period  $[T_{i-1}, T_i]$ , i.e.,

$$p_j := \text{CDS}^{B_j}(T_i; T_{i-1}).$$

<sup>3</sup> We assumed that the protection fee is paid at the end of the protection period, it is straight forward to include periodic protection fees.

Let

$$V_i(T_i) := \sum_j V_i^{B_j}(T_i).$$

The general valuation algorithm including funding and counterparty risk is then given as

$$\begin{aligned} \frac{V_i^d(T_{i-1})}{N(T_{i-1})} = & \mathbb{E}^{\mathbb{Q}^N} \left( \frac{\max(V_i(T_i), 0)}{N(T_i)} P^A(T_i; T_i) \right. \\ & \left. + \frac{\min(V_i(T_i), 0)}{N(T_i)} P^\circ(T_i; T_i) \mid \mathcal{F}_{T_{i-1}} \right). \end{aligned} \quad (4)$$

In our valuation the time  $T_{i-1}$  value being exposed to entities  $B_j$  counterparty risk is given by

$$\begin{aligned} \frac{V_i^{B_j}(T_{i-1})}{N(T_{i-1})} := & \mathbb{E}^{\mathbb{Q}^N} \left( \frac{\max(V_i(T_i), 0) - \max(V_i(T_i) - V_i^{B_j}(T_i), 0)}{N(T_i)} P^A(T_i; T_i) \right. \\ & \left. + \frac{\min(V_i(T_i), 0) - \min(V_i(T_i) - V_i^{B_j}(T_i), 0)}{N(T_i)} P^\circ(T_i; T_i) \mid \mathcal{F}_{T_{i-1}} \right). \end{aligned}$$

In other words,  $V_i^{B_j}(T_{i-1})$  is the true portfolio impact (including side effects of funding) if the flows  $X_{l,k}^{B_j}$ ,  $l \geq i$ , are removed from the portfolio.

In the case where the mismatch of contracted default value  $V_{\text{CLSOUT},i}^B(T_i)$  and netted non-default value  $V_i^B(T_i)$  is zero we arrive at

$$V_i^{B_j}(T_i) := \min(R_i^{B_j}(T_i), 0) + (1 - p_j) \max\left(\sum_k X_{i,k}^{B_j} + V_{i+1}^{B_j}(T_i), 0\right).$$

- in this case we get an additional discount factor on the positive part (exposure) of the netted value.

### 3.4.3 Interpretation

From algorithm (4) it is obvious that the valuation of funding (given by the discounting using either  $P^\circ$  or  $P^A$ ) and the valuation of counterparty risk (given by buying/selling protection at  $p$ ) cannot be separated. Note that

- We not only account for the default risk with respect to our exposure ( $V_{\text{CLSOUT},i}^B(T_i)$ ), but also to the loss of a potential funding benefit, i.e., the impact of default on funding.
- Buying protection against default has to be funded itself and we account for that.

The algorithms (4) values the so called wrong-way-risk, i.e., the correlation between counterparty default and counterparty exposure via the term  $p_j \max(R_i^{B_j}(T_i), 0)$ .

## 4 The Relation of the Different Valuations including Counterparty Risk

Let us summarize the relation of the two different discounting in the presents of counterparty risk. The mark-to-market value of a time  $T_i$  cash flow is

cash flow	discount factor over $[T_{i-1}, T_i]$
outgoing ( $C(T_i) < 0$ )	$P^A(T_{i-1}, T_i)$
incoming ( $C(T_i) > 0$ )	$P^B(T_{i-1}, T_i)$

In this situation a liability of **A** is written down, because in case of liquidation of **A** its counterparts accepts to receive less than the risk free discounted cash flow today.

The hedging (replication) value of a time  $T_i$  cash flow depends however on our net cash position, because the net cash position decides if funding cost apply or a funding benefit can be accounted for. The net cash position has to be determined with the backward algorithm (2) where each cash flow  $X_i$  is adjusted according to his (netted) counterparty risk. Using  $P^B(T_i; T_i)P^\circ(T_{i-1}, T_i) = P^B(T_{i-1}, T_i)$  we can formally write

cash flow	discount factor over $[T_{i-1}, T_i]$	
	positive net cash in $T$	negative net cash in $T_i$
outgoing ( $C(T_i) < 0$ )	$P^A(T_{i-1}, T_i)$	$P^\circ(T_{i-1}, T_i)$
incoming ( $C(T_i) > 0$ )	$P^B(T_i; T_i)P^A(T_{i-1}, T_i)$	$P^B(T_{i-1}, T_i)$

The two valuation concepts coincide when  $P^A(T_{i-1}, T_i) = P^\circ(T_{i-1}, T_i)$ , i.e., we do not have funding cost. They also coincide if an outgoing cash flow appears only in the situation of positive net cash in  $T_i$  (funding benefit) and an incoming cash flow appears only in the situation of negative net cash  $T_i$  (funding benefit).

Put differently: The liquidation valuation neglects funding by assuming funding benefits in all possible situations.

## 5 One Product - Two Values

Given the valuation framework discussed above a product has at least two values:

- the product can be evaluated “mark-to-marked” as a single product. This value can be seen as a “fair” market price. Here the product is valued according to Section 2. This is the product’s *idiosyncratic value*.
- the product can be evaluated within its context in a portfolio of products owned by an institution, i.e., including possible netting agreements *and* operating costs (funding). This will constitute the value of the product for the institution. Here the value of the product is given by the change of the portfolio value when the product is added to the portfolio, where the portfolio is valued with the algorithm (2). This is the products *marginal value*.

However, both valuations share the property that the sum of the values of the products belonging to the portfolio does not necessarily match the portfolio’s value. This is

clear for the first value, because netting is neglected all together. For the second value, removing the product from the portfolio can change the sign of netted cash flow, hence change the choice of the chosen discount factors.

## 5.1 Valuation of a Bond

To test our frameworks, lets us go back to the zero coupon bond from which we started and valued it.

### 5.1.1 Valuation of a Bond at Mark-To-Market

Using the mark-to-market approach we will indeed recover the bonds market value  $-P^A(T; 0)$  (this is a liability). Likewise for  $P^B(T)$  we get  $+P^B(T; 0)$ .

### 5.1.2 Valuation of a Bond at Funding

Factoring in funding costs it appears as if issuing a bond would generate an instantaneous loss, because the bond represents a negative future cash flow which has to be discounted by  $P^\circ$  according to the above. This stems from assuming that the proceeds of the issued bond are invested risk free. Of course, it would be unreasonable to issue a risky bond and invest its proceeds risk free.

However, note that the discount factor only depends on the *net* cash position. If the net cash position in  $T$  is negative, it would be indeed unreasonable to increase liabilities at this maturity and issue another bond.

Considering the hedging cost approach we get for  $P^A(T)$  the value  $-P^\circ(T; 0)$  if the time  $T$  net position is negative. This will indeed represent loss compared to the mark-to-market value. This indicated that we should instead buy back the bond (or not issue it at all). If however our cash position is such that this bond represents a funding benefit (in other words, it is needed for funding), it's value will be  $P^A(T; 0)$ .

For  $P^B$  we get

$$N(0)E^{\mathbb{Q}}\left(\frac{P^B(T; T)P^A(T; T)}{N(T)} \mid \mathcal{F}_0\right)$$

Assuming that A's funding and B's counterparty risk are independent from  $P^\circ(T)$  we arrive at

$$P^B(T; 0)\frac{P^A(T; 0)}{P^\circ(T; 0)}$$

which means we should sell B's bond if its return is below our funding (we should not hold risk free bonds if it is not necessary).

## 5.2 Convergence of the two Concepts

Not that if A runs a perfect business, securing every future cash flow by hedging it (using the risk free counterpart  $P^\circ(T; T)$ ), and if there are no risk in its other operations, then the market will likely value it as risk free and we will come close to  $P^A(T; T) = P^\circ(T; T)$ . In that case, we find that both discounting methods agree and symmetry is restored.

However, there is even a more closer link between the two valuations. Let us consider that entity **A** holds a large portfolio of products  $V_1, \dots, V_N$ . Let  $V_1(0), \dots, V_N(0)$  denote the mark-to-market (liquidation) value of those products. Let  $\Pi[V_1, \dots, V_N](0)$  denote the hedging value of the portfolio of those products. If the portfolio's cash flows are hedged in the sense that all future net cash flows are zero, then, neglecting counterparty risk, we have (approximately)

$$V_k(0) \approx \Pi[V_1, \dots, V_N](0) - \Pi[V_1, \dots, V_{k-1}, V_{k+1}, \dots, V_N](0).$$

Thus, the mark-to-market valuation which includes “own-credit” for liabilities corresponds to the marginal cost or profit generated when removing the product from a large portfolio which includes funding costs. However, portfolio valuation is non-linear in the products and hence the sum of the mark-to-market valuation does not agree with the portfolio valuation with funding costs.

We proof this result only for product consisting of a single cash flow. A linearization argument shows that it then hold (approximately) for products consisting of many small cash flows.

If the portfolio is fully hedged the all future cash flows are netted. In other words, the entity **A** attributed for all non-netted cash flows by considering issued bonds or invested money. Then we have  $V_j^d(T_j) = 0$  for all  $j$ . Let  $V_k$  be a product consisting of a single cash flow  $C(T_i)$  in  $T_i$ , exchanged with a risk free entity. If this cash flow is incoming, i.e.  $C(T_i) > 0$  then removing it the portfolio will be left with an un-netted outgoing cash flow  $-C(T_i)$ , which is according to our rules discounted with  $P^o(T_i)$ . Likewise, if this cash flow is outgoing, i.e.  $C(T_i) < 0$  then removing it the portfolio will be left with an un-netted incoming cash flow  $C(T_i)$ , which is according to our rules discounted with  $P^A(T_i)$ .

Hence the marginal value of this product corresponds to the mark-to-market valuation.

## 6 Credit Valuation Adjustments

The valuation defined above includes counter party risk as well as funding cost. Hence, valuing a whole portfolio using the above valuation, there is no counter party risk adjustment.

However, the valuation above is computationally very demanding. First, all products have to be valued together, hence it is not straight forward to look at a single products behavior without valuing the whole portfolio.

Second, even very simple products like a swap have to be evaluated in a backward algorithm using conditional expectations in order to determine the net exposure and their effective funding costs. This is computationally demanding, especially if Monte-Carlo simulations is used.

As illustrated above, the valuation simplifies significantly if all counterparts share the same zero coupon bond curve  $P(T; t)$  and/or the curve for lending an borrowing agree. A credit valuation adjustment is simply a splitting of the following form

$$V(t) = V|_{P=P^*}(t) + \underbrace{(V(t) - V|_{P=P^*}(t))}_{\text{CVA}}$$



where  $V|_{P=P^*}(t)$  denotes the simplified valuation assuming a single discounting curve  $P^*$  (neglecting the origin or collateralization of cash flows).

While the use of a credit valuation adjustment may simplify the implementation of a valuation system it brings some disadvantages:

- The valuation using the simplified single curve, in general, is not correct.
- Hedge parameters (sensitivities) calculated such valuation, in general, are wrong.

In order to cope with this problem we propose the following setup:

- Construction of proxy discounting curve  $P^*$  such that the CVA is approximately zero.
- Transfer of sensitivity adjustments calculated from the CVA's sensitivities.

## 7 Modeling and Implementation

So far we expressed all valuation in terms of products of cash flows and zero coupon bond processes like  $P^A(T; t)$ . The value of a stochastic time  $T$  cash flow  $C(T)$  originating from entity  $A$  was given as of time  $T$  as

$$C(T)P^A(T; T)$$

and the corresponding time  $t < T$  value was expressed using risk neutral valuation

$$N(0)E^{\mathbb{Q}^N} \left( \frac{C(T)P^A(T; T)}{N(T)} \mid \mathcal{F}_0 \right).$$

Our presentation was model independent so far. Depending on the cash flow the term  $C(T)P^A(T; T)$  may give rise to valuation changes stemming from the covariance of  $C(T)$  and  $\frac{P^A(T; T)}{N(T)}$ .

For an implementation of the valuation algorithm consider a time discretization  $0 =: t_0 < t_1 < \dots < t_n$ . We assume that the discretization scheme of the model primitives models the counterparty risk over the interval  $[t_i, t_{i+1})$  as an  $\mathcal{F}_{t_i}$ -measurable survival probability such that we have for all  $t_{i+1}$  cash flows  $C(t_{i+1})$  that

$$\begin{aligned} & N(t_i)E^{\mathbb{Q}^N} \left( \frac{C(t_{i+1})P^A(t_{i+1}; t_{i+1})}{N(t_i)} \mid \mathcal{F}_{t_{i+1}} \right) \\ &= N(t_i)E^{\mathbb{Q}^N} \left( \frac{C(t_{i+1})}{N(t_{i+1})} \mid \mathcal{F}_{t_i} \right) \exp \left( - \int_{t_i}^{t_{i+1}} \lambda^A(s; t_i) ds \right). \end{aligned} \quad (5)$$

The expression  $\exp \left( - \int_{t_i}^{t_{i+1}} \lambda^A(s; t_i) ds \right)$  represents an additional “discounting” stemming from the issuers credit risk / funding costs. It can be interpreted as and (implied) survival probability (see Chapter 28 in [4]).<sup>4</sup>

Hence any counterparty-risk-free valuation model can be augmented with funding costs, counterparty risk and collateralization effects by two modifications:

<sup>4</sup> A very simple model is to assume that  $\exp \left( - \int_{t_i}^{t_{i+1}} \lambda^A(s; t_i) ds \right)$  is deterministic.

- The model is augmented by a simulation of the (conditional) one step (forward) survival probabilities (or funding spreads), e.g.,  $\exp\left(-\int_{t_i}^{t_{i+1}} \lambda^A(s; t_i) ds\right)$ .
- The valuation is performed using the backward algorithm (2), where in each time step the survival probabilities and/or funding adjusted discount factors are applied according to (5).

## 8 Other Work

The topic has evolved in recent years and there are now many papers discussing valuation under counterparty risk and collateralization. The backward algorithm to value under different curve for borrowing and lending was already given in the textbook [4]. We will thus just list a few recent papers and refer the reader to references therein. Recent paper discuss the effects of the correlation term induced by a mismatch of the index and the discounting curve, i.e., convexity adjustments, see, e.g., [9]. The usual setup of other papers is to consider a two or three curve valuation framework: one (forward) curve for the indices (forward rates and swap rates), one (discounting) curve for collateralized deals and one (discounting) curve for funded deals, see, e.g., [1, 10]. However, as we have illustrated, there may be no such thing as a unique discounting curve. For the modeling of rates (e.g., through basis swap spreads) see, e.g., [6].

In [8] Morini and Prampolini showed that “own-credit”, i.e., discounting outgoing cash flows (liabilities) with its own funding can be interpreted as a funding benefit. The paper clarifies the role of CDS-spreads and funding spreads in discounting. Since netting is not considered and since it is assumed that the borrower will always account for a funding benefit and the lender always accounts for funding a unique discounting curve can be constructed.<sup>5</sup>

For the valuation of CVAs using modeling the default time / stopping time to value the contract under default see [2] and Section 8 in [7] (“two-way payment clause”). In the latter a homogeneity assumption is made resulting in  $P^A(T; t) = P^B(T; t)$ . In contrast to the CVA approach modeling default times we considered market prices of zero coupon bonds only and the valuation would require a model of the zero coupon bond process (one way is to modeling default times, another is to model spreads and survival probabilities). With the possible exception of the Section 7 on “Modeling” we did not explicitly model the impact of liquidity or default risk.

## 9 Conclusion

We considered the valuation of cash flows including counterparty risk and funding. We shed some light on the *own credit risk paradox* that the mark-to-market value of a portfolio increases if its owner’s credibility decreases. After our discussion the situation now appears much clear: This increase in value is reasonable when considering the portfolios liquidation since lenders are willing to accept a lower return upon liquidation in exchange for the increased credit risk.

<sup>5</sup> The assumption is to some extent asymmetric, since accounting for a funding benefit would mean that some other deal does not require funding.

If we value the portfolio under a hedging perspective (where hedging to some extent means funding) we see that the portfolio value decreases if its owner's credibility decreases. This is also reasonable since funding cost (operating costs) have risen.

The two notion of valuation can co-exist. They do not contradict. One discounting should be used for mark-to-market valuation. The other should be used for risk management and the governance (managing) of positions.

To see the effect of a single deal on the cash flow management the bank could use a curve for borrowing and lending and every deal would have to be valued according to the algorithm (2).

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## Notes

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