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DVA in the Structured Notes Issuance Portfolio

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Abstract

This thesis focus on the issuer credit risk in financial derivatives held by a structured notes desk. Post-crisis derivative valuation includes valuation adjustments for credit, collateral and funding risk, commonly referred to as xVA. Debt Value Adjustment (DVA) is the integral cost of the issuer's own credit risk in a derivative as it is held on the issuer's balance sheet. In this thesis the DVA of the structured notes desk is defined and the factors that affect it are identified. Systematic strategies for minimizing the variance of the DVA under the constraints the structured note desk faces in reality are considered and tested on a sample portfolio. The results from the hedging strategies show that the variance of the DVA can be reduced. The most successful hedge utilizes index futures and attempts to capture regional systematic market risk. However, the overall effectiveness of the hedges is modest, but still the findings should be guiding when setting up a hedging strategy in practice.

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Introduction

The over-the-counter (OTC) market for financial derivatives was a contributing factor in the 2007-2008 financial crisis (Financial Crisis Inquiry Commission, 2011). In response to this, these markets have been subject to substantial political discussions and research, ultimately leading to new policies and regulations (Helleiner and Pagliari, 2011). Additionally, a pattern that had not been seen before the crisis was that the previously very low spread between the banks funding rates and the risk free rates increased dramatically during the crisis years (Hull and White, 2013). Banks involved in the OTC derivative markets have had to adapt their operations to the paradigm shift that the financial crisis caused. One of many business directly affected is the structured notes issuances that rely on OTC derivatives for hedging cash flows.

One of policy-makers' main focuses in the post-crisis era has been to reduce the previously overlooked counterparty credit risk inherit in OTC derivatives. The outcome is a framework for quantifying and pricing of credit risks in derivatives. Banks original valuation framework with origins in Black and Scholes (1973) option pricing now includes so called valuation adjustments. Credit value adjustment (CVA) was the first commonly applied valuation adjustment. CVA reflects the current price of taking on the integral counterparty credit risk of a specific derivatives contract. After CVA, there has been several valuation adjustments added to the framework, collectively referred to as xVA[1]. For example, other xVAs had to be considered due the fact that exposure in some derivative trades are bilateral. When the two parties of a trade both want to account for the other party's credit risk it follows that the price where both are willing to execute a trade must include the value of respective party's own credit risk. The value of a parties own credit risk when accounted for in a derivative trade is referred to as debt value adjustment (DVA) in the xVA framework. Another xVA aims at capturing the cost of posting collateral. This is referred in different literature as collateral rate adjustment (CRA) or simply collateral value adjustment (collVA).

The implications of implementing the xVA framework are material. For example, JP Morgan recorded a 1.5$ billion loss from implementing a xVA framework in their profit and loss (P/L) accounting at the derivative and structured notes desks in 2014 (Whittall, 2014).

[1] The x in xVA is replaced with the letter representing the specific adjustment (eg. Credit, Debt, Collateral) and VA is abbreviation for valuation adjustment.

Nevertheless, the different valuation adjustments are still debated both in the industry and the academic world and there are still many open research questions.

This thesis focus specifically on the issuer default risk at a structured notes desk. Castagna (2012) concludes that a derivatives issuer cannot replicate its own credit risk. With this initial constraint, the possibilities of hedging DVA are explored. There are two research problems covered in this thesis. The first is how DVA in the perspective of a structured notes desk originates and how it can be defined and measured. The second problem is how systematic hedging strategies with the aim of minimizing the variance of the DVA in the structured notes portfolio can be utilized and evaluated in practice.

The objectives of this thesis are three-fold. The first objective is to assess and develop an understanding of the emergence of DVA as a part in the xVA framework. This is necessary in order to carry out further analysis on the implications of xVA for the structured notes desk. The origination of derivative valuation starting in Black and Scholes option valuation principles will be covered, in order to understand its inherent issues and the motivations for the xVA framework. Current literature on xVA will be assessed and applied in the perspective of the structured notes desk.

The second objective is to setup a valuation framework for the structured notes desk which incorporates DVA. In order to do this a CVA/DVA model should be considered. A case study of the structured notes portfolio of a Nordic issuer will be carried out where the valuation framework can be implemented and assessed. This leads to the third objective which is to set grounds for the development of a hedging strategy that could be used in practice for hedging DVA volatility at a structured notes desk. Understanding how this can be done is very relevant in order to reduce the unwanted P/L fluctuations in the structured notes book.

The scope of the first part of the thesis is at first broad at first. However, this will quickly narrow down to focus on DVA and structured notes in the context of an issuer. The scope of the second part is limited to the structured notes desk. While the instruments considered might have effect on other parts of a bank's balance sheet, only the balance sheet of the structured notes desk is considered in the analysis.

The first parts of the research relies on literature review as research method. Mathematical concepts are applied when setting up the CVA/DVA model as well as the valuation framework. The model and framework are implemented through R programming. Excel is used as a complement for some applications, especially when the hedging strategies are implemented. The financial data is mainly acquired from Bloomberg and the data on the structured notes portfolio is provided by the issuer.

The remainder of the thesis is structured as follows. Section 2 introduces the background of the problem as well as previous research and has three sub-sections. First, the research and industry events that have set the grounds for derivatives pricing as it looks today are assessed. In the second sub-section the xVA framework and CVA/DVA models are covered. Finally, structured notes are introduced and discussed in terms of the effects from applying the xVA framework at the structured notes desk level. Section 3 describes the data used in the analysis. Section 4 covers the methodology for setting up a valuation framework including xVA and presents the strategies that are used in the hedging strategies. Section 5 presents the results of the analysis. This is followed by a discussion and conclusion of the results.

Background and Existing Research

Derivative Pricing Principles

One can generally divide the financial markets into two broad categories. The first are the markets of stocks, bonds, commodities, exchange rates etc. In the context of this thesis the instruments traded in the first category of markets are referred to as underlying assets. The second category are the markets where financial instruments dependent on the underlying assets are traded, the derivative markets. (Baxter and Rennie, 1996)

While the derivative transactions have a long history[2], the first standardized futures contracts emerged at the Chicago Board of Trade (CBOT) during the second half of the 19th century. The instruments traded in Chicago were used by farmers as a way to lock in prices of grain with future delivery. In 1973, CBOT established the Chicago Board Options Exchange, the first market for standardized option contracts. Since then the derivate markets have grown tremendously throughout the world. (Hull, 2009)

The paper, "*The pricing of options and corporate liabilities*" by Black and Scholes from 1973 is one of the most influential in derivatives pricing. Black and Scholes derives a closed form valuation formula for European call and European put options with two different approaches. First by replicating the derivative with a portfolio of stocks and bonds. The second derivation relies on the CAPM. Black and Scholes use the following assumptions throughout their paper:

1. Short term interest rate is known and constant throughout time (and risk free)
2. The price of the asset follows a random walk in continuous time
    a. The variance of the price is proportional to the square of the stock price
    b. This means that the future stock price is log-normally distributed
    c. The variance of the stock return is constant
3. The stock pays no dividend
4. There are no transaction cost and it is possible to short sell the stock at no additional cost
5. It is possible to lend and borrow at the risk-free rate

These assumptions are relevant throughout the remainder of this paper, although some will not be strictly applied at all times.

[2] Weber (2009) traces future-like transactions back to 19th century BC

There are two findings in Black and Scholes paper that have had a substantial impact on the field of derivative pricing. The first is the idea of dynamic replication.[3] The basis of their argumentation is that one can construct a portfolio, consisting of a long position in a stock and a short position in the option of the same stock, which value will be unaffected by very small and instant changes in the price of the stock. The ratio between stocks and options that holds the portfolio immune to changes in the price of the stock is however changing over time. Continuous hedging of this ratio maintains the price insensitivity at every point in time. This process is referred to as dynamic replication.

The second point is the no-arbitrage argument. Because of the dynamic replication, the value of the portfolio consisting of an option and its replicating hedge, depends only on the passing of time and *"the values of known constants"*. Since there is no element of risk in the return of such portfolio, it must have a pay-out equal to the short term risk free rate. It can be argued that if the portfolio was mispriced and paid a higher (lower) return compared to the risk free rate, the rational decision of an investor would be to buy (sell) the portfolio to realize risk-free return above the risk-free interest rate. Consequently, under the no-arbitrage assumption, investors would continue buying the portfolio until the price would be at such level where the expected return is equal to the risk-free rate. (Black and Scholes, 1973)

Putting these two conclusions together, Black and Scholes end up with a differential equation for the price of the option. By solving the equation they formulated the Black-Scholes formula which has had a great influence on derivative pricing. (Hull, 2009) The pricing principles have lead the way for many expansions in derivative pricing and they will set the foundation for the analysis of this paper. In essence the outcome is that any instrument can be priced by replication of assets with known price dynamics and there will only exist one price of any traded element at each point in time. (Harrisson and Kreps, 1979)

Another important principle in derivative pricing is risk-neutrality. There is an important distinction between two probability measures in quantitative finance, the risk-neutral world and the

[3] Merton is credited by Black and Scholes for coming up with the dynamic hedging principle and many times the Black-Scholes model is referred to as the Black-Scholes-Merton model due to Merton's involvement in bringing forward and expanding the model. See Merton (1973).

real world.[4] In the risk-neutral world the investor is indifferent to the risk of the investment as long as the expected return equals the risk free rate. (Hull, 2009) In the real world we know that this is not always true, a clear example would be the gambling industry. In this paper, both risk-neutral and real world measures will be considered, however, separately and in different stages of the analysis. In the discussion on asset prices processes risk neutrality is assumed and the difference between the two measures will be important when the input data for the Monte Carlo simulation is discussed.

Benchmark Interest Rates

In the Black-Scholes model the value of an option is not dependent on the expected return of the underlying stock. Instead it is the risk free rate that is used as an input in the model. Defining a risk free rate is tricky. In Corporate Finance it is common practice to simply rely on government bonds as representation for risk free instruments (Demodaran, 2008). However, for derivative pricing government bonds are not ideal. A requirement is that the risk free rate is a market rate that can be both bought and sold, therefore other proxies for risk free rate needs to be considered (Hull, 2009). Below follows a description of three common benchmarks for the risk-free rate. The purpose of comparing three different rates is two-fold. Firstly, as described above, derivative pricing is highly dependent on the choice of risk free rate. Secondly, the comparison between the benchmark rates highlights some of the peculiarities in the financial markets that have led to the emergence of the xVA framework.

London Interbank Offered Rate – LIBOR

The London Interbank Offered Rate (LIBOR) rate is a well-known interest rate fixing based on the interest rates for bank to bank lending in London (Gyntelberg and Wooldridge, 2008). A panel of 11 to 17 banks contribute their unsecured funding rates on a daily basis and the average of 5 to 9

[4] The real world probability measures provides the basis of Markovitz's modern portfolio theory (1952) and its extensions such as the CAPM and is commonly denoted as $\mathbb{P}$. The risk-neutral measure, $\mathbb{Q}$, is based on the assumptions of no-arbitrage and that investor's risk-sensitivity are equal all assets, this must hold at all times. The risk-neutral measure has been vital to the emergence of derivative pricing with pioneers such as Merton (1969), Black and Scholes (1973). Meucci (2011) provides a good summary of the practical applications of the different probability measures.

contributions[5] are used to calculate fixings in five different currencies and several terms. Each panel bank is asked:

> *"At what rate could you borrow funds, were you to do so by asking for and then accepting interbank offers in a reasonable market size just prior to 11 am London time?"*

The LIBOR rates are used as a standard interest rate benchmark in derivative and loan transactions and are calculated by the Intercontinental Exchange (ICE, 2016). The equivalent interbank rate in SEK is called Stockholm Interbank Offered Rate (STIBOR) (Swedish Bankers' Association, 2015). Similarly in DKK, the interbank rate is Copenhagen Interbank Offered Rate (CIBOR) (Finansrådet, 2014) and NOK, Norwegian Interbank Offered Rate (NIBOR) (Finans Norge, 2016). While there exists a LIBOR rate in EUR, the most common fixing is the Euro Interbank Offered Rate (EURIBOR) (European Banking Federation, 2012).

LIBOR rates have been used as proxies for the risk free rates by banks, even though they are not completely risk free. The banks themselves are not default free, hence their borrowing rates must contain an element of risk. One of the reasons for its popularity would be that the LIBOR rates corresponds to the funding cost of the bank. (Hull, 2009)

Repo Rates

A repurchase agreement, often referred to as a repo, is a contract where two parties agree on a transaction where a security is initially sold and then bought back at a later point in time. The prices are determined at the inception of the contract and the difference in the two prices corresponds to the interest earned or paid for the transaction. So in essence, the party that holds the security before it enters the contract is provided a loan during the life time of the contract and vice versa. Since the part that provides the loan receives the security and would keep that in the case that the other party would default, it is considered a very safe loan. The rate paid for the loan is referred to as a repo rate.

There is literature suggestion that repo rates is a good proxy for risk free rates. By testing the expectation hypothesis[6], Longstaff (2000) finds arguments for using repo rates to measure the

[5] The top 25% and bottom 25% of the contributions are excluded.
[6] Expectation hypothesis is formulated already in 1986 by Fisher and has been tested many times since, see for example Fama (1984).

risk free rates. Additionally, another credible argument is that compared to the LIBOR rates, which are unsecured, the repo rates are collateralized and should therefore have less credit risk. (Hull and White, 2013)

However, there are several reasons for why the repo rates are not suitable. Hull and White (2013) argues that the repo rates are not consistent and dependent on the security which is used as collateral. Furthermore, it is difficult to have a complete term structure for repo rates. For these reasons the repo rates should not be considered a good proxy for the risk free rates.

Overnight Indexed Swap – OIS

An Overnight Indexed Swap (OIS) is an interest rate swap that pays a fixed leg referred to as the OIS rate and a floating leg. The floating rate index is a daily compounded overnight interest rate. In EUR the typical overnight rate is Euro Overnight Index Average (EONIA) which is calculated together with the EURIBOR rates. (Hull and White, 2013)

When two parties trade an OIS they agree on the fixed rate for the length of the contract. At the maturity of the contract the geometric average of the overnight rate is calculated and if it is greater than the fixed rate, the floating rate payer will pay the difference between the two legs to the fixed rate payer and if the fixed rate leg is greater, vice versa. In this way, only the difference between the two legs are paid at the maturity of the contract. (Nasdaq OMX, 2014)

OIS exists for maturities up to several years. For longer swaps the payments are usually done on a quarterly basis rather than at maturity. Since there is no exchange of notional the credit risk in the instrument due to the expected default of a party is low. Central clearing and collateralization reduces the credit risk even further. (Hull and White, 2013)

Subsequently, the premium to expect in the OIS rate would be related to the credit risk in the overnight rate. However, the overnight rates are generally considered to include very little credit risk due to their short term. Since the credit risk is very low, OIS rates are considered a good proxy for the risk free rates. (ibid.)

Financial crisis: Default risk matters

The financial crisis in 2007-2008 had a significant impact on the entire world economy (Stiglitz, 2009). OTC derivatives have been pointed out as one of the contributing factors to the crisis, in particular the lack of legislation and governance in the market (Financial Crisis Inquiry Commission, 2011). Starting in the 1980s up to the crisis the US financial markets have enjoyed extensive deregulation. This coupled with a fast development in financial innovation were the underlying problems with the OTC derivative markets (Crotty, 2009).

Coming back to the discussion on risk free rates, the financial crisis showed a peculiar pattern in the spread between the LIBOR rates and OIS rates that highlights the problem that underlies the purpose of this thesis. As can be seen in Figure I, the spread between the two rates is close to 0 in the years before the crisis. However, in August 2007 and onwards, the spread spikes significantly.

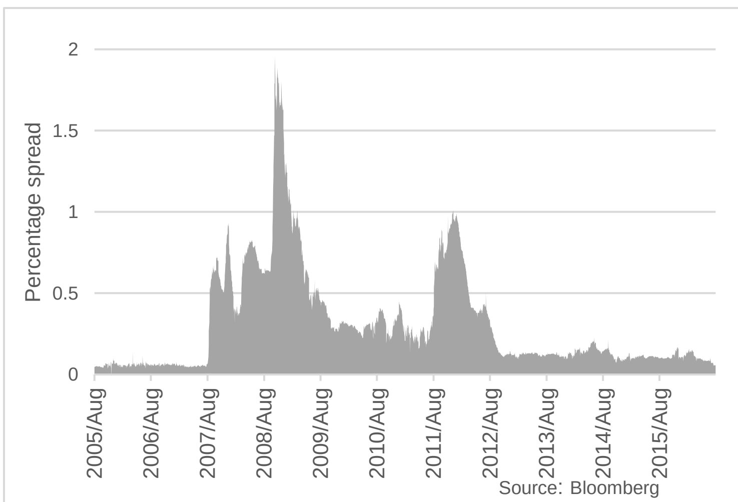


Figure I: Spread between 3m EURIBOR and 3m OIS rate during the period August 2005 and August 2016

During the crisis banks became fully aware that investments that were considered low risk investments, indicated by a high credit rating, in fact had an overlooked possibility of defaulting (Financial Crisis Inquiry Commission, 2011). The low LIBOR-OIS spread in the pre-crisis years would imply that the banks could lend almost at the risk free rate. Nonetheless, the sharp divergence reflects the perceived credit risk in the interbank market. This is a clear example that the LIBOR rate is not a proper proxy for the risk free rate and that the credit risk in high-rated institutions is not to be overlooked (Hull and White, 2013). Additionally, the divergence between funding and policy rates during and after the crisis challenges the prior relationship of the rates, which is a new complexity for the banks (Illes et al., 2015).

In the aftermath of the crisis, the financial industry has been subject to a broad range of new regulations (Ferran et al., 2012). New restrictions for capital requirements at banks have been put in place with the goal of reducing the probability of a new crisis and the overall swings in growth rates (BIS, 2010). Two-thirds of the credit losses during the crisis were due to deterioration in credit quality rather than actual defaults (BIS, 2012). Under Basel III capital charges for counterparty risk has been put into place. While not entirely new to the banks, the credit risks and capital charges have been a focus point in the recent years, leading to a new paradigm in the banking industry and derivative pricing. (Gregory, 2016)

The xVAs

The Black-Scholes value of a derivative assumes that there is no uncertainty that any payments under the derivative contract will actually be paid. We will refer to this value as the no-default value and denote the no-default value of an OTC derivative f. From the discussion on benchmark interest rates we have that the appropriate discount rate for f is the OIS rate.

Prior to the crisis banks thought of the risk that the credit worthiness of their counterparties would decline as insignificant. Banks were still concerned about the default of a counterparty. However, it was not a primary concern to hedge the changes in their counterparties' credit spreads (Ruiz, 2015). The large banks have calculated credit charges for counterparty risk on derivative transactions since the 1990s and even before the crisis some banks calculated valuation adjustments for credit risk. However, it was the changes that happened during the crisis that shifted the focus towards credit risk in derivative transactions. In the light of this focus, the industry have established an approach to incorporate credit risks into the pricing framework for financial derivatives. The pricing principles of Black and Scholes still holds, but what is added are so called valuation adjustments that quantifies the price of credit risk in the specific derivative. (Gregory, 2016)

There are several value adjustments in use, not only accounting for the credit risk in a transaction, commonly referred to as xVA. In the post-crisis era many of the larger banks have trading desks focused only on managing the different xVAs. This is possible by dividing the value of an instrument into its no-default value and its xVAs. The traditional trading desks then manage the risk of the no-default derivative and the xVA desks handle each xVA on an aggregate level. (Ruiz, 2015) This concludes the history on the emergence of xVAs. In the next sub-section follows a description of some of these valuation adjustments

Credit Value Adjustment and Debt Value Adjustment

According to the International Financial Reporting Standards (IFRS) the fair value of an asset or liability should take into account the “non-performance” risk of the contingent claims. This was implemented in IFRS 13 that was effective as of January 1st 2013 (Deloitte, 2016). In practice, this means that the value of an OTC derivative contract should be adjusted for the cost of risk that the transfers under the contract will not be carried out in completion. This adjustment of the value is referred to as the Credit Value Adjustment (CVA) (EY, 2014). If a bank buys a derivative with a no-default value f, the value of that asset, V_A, on its balance sheet *is* given by,

$$V_A = f - CVA$$

In a similar fashion, the IFRS states that the non-performance risk associated with the banks own obligations under the contract also needs to be taken into account (Deloitte, 2016). This adjustment for the issuing bank would be the same as the CVA that the counterparty of the trade would experience (Ruiz, 2015). The terminology for this adjustment varies, but it is often called Debt Value Adjustment or DVA.[7]

The notion of DVA can seem a bit counter-intuitive at first. Let us assume that a bank is obliged to pay its counterparty under the derivative contract. For the bank the discounted expected cash flow under the derivative contract is considered a liability today. The no-default value of the cash flow would be discounted with the risk free rate. When the banks consider its own credit risk the cash flow must be discounted even further. The liability for the bank is therefore smaller when it takes into account its own default risk and if the riskiness of the bank would increase, its liability would decrease. The difference between the no-default value of the cash flow and the default contingent value of the cash flow is the DVA, which in this case is a positive value adjustment for

[7] For a transaction that will always be an asset for the buyer CVA can be referred to as unilateral CVA. When a derivative can be both an asset and a liability throughout its lifetime the total CVA can be referred to as bilateral CVA. Ruiz (2015) among other literature refer to DVA as CVA_{liab}.

the bank. The value on the balance sheet of an instrument that can be of both positive and negative value for a bank, is then given by,

$$V = f - CVA + DVA$$

Collateral Rate Adjustment

In order to mitigate CVA and DVA banks usually have collateral agreements to reduce the credit exposures. Collateral agreements are today an essential part in the OTC derivative market. As can be seen in Figure II the levels of collateral are considerably higher after the crisis, much due to regulatory changes (ISDA, 2015). However, in the most recent years collateral amounts have declined slightly because of the increase of central counterparty clearing (Ibid.). For exchange traded instruments, the exchanges' clearing agent usually sets up the rules regarding collateral posting. In the OTC market the International Swaps and Derivatives Association (ISDA) publishes the widely used ISDA's Master Agreement. Market participants enter Master Agreements bilaterally in order to standardize their OTC transactions. The ISDA Master Agreement includes a Credit Support Annex (CSA) which is optional to include and stipulates the details for collateral arrangements. This means that one bank can have different rules for collateral postings for different counterparties (Monnet, 2011). If the value of a derivative is negative to a defaulting party, the other party may claim the costs for replacing that derivative from the collateral. (Hull and White, 2014)

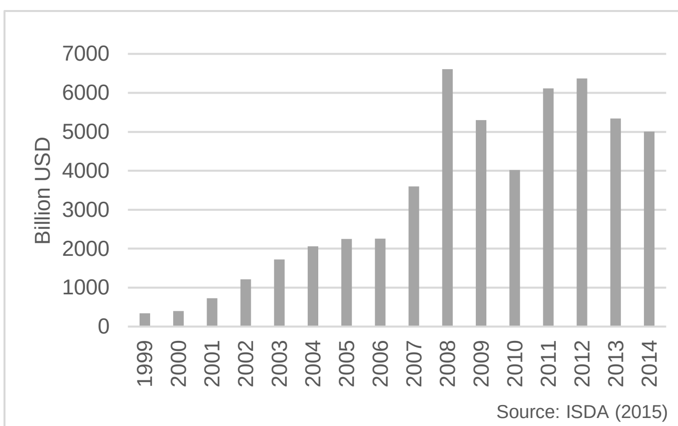


Figure II: Collateral assets for non-cleared derivative trades during the period 1999 to 2014

When the relationship between two counterparties is asymmetric in terms of creditworthiness the collateral requirements usually differ for the counterparties of the CSA, in some cases only one counterparty is required to post collateral. A CSA can also define a threshold level under which no collateral will be posted. There are as well restrictions on which instruments that can be posted as collateral. If the interest rate paid for the collateral is different from the risk free rate it will be at an additional cost for the party posting collateral. It follows from this that another value adjustment is the Collateral Rate Adjustment (CRA). All the factors described above needs to be taken into account when calculating the CRA, which makes it a quite complex task. (Ibid.)

Nonetheless, the balance sheet value of an instrument with credit and collateral adjustments is given by,

$$V = f - CVA + DVA - CRA$$

Other xVAs

While outside the scope of this thesis, the field of xVAs in literature and industry practice extends beyond the value adjustments covered so far. For example, some literature discuss the Capital Value Adjustment (KVA). KVA captures the costs of posting capital related to the current and future regulations that applies to the transaction in question (Ruiz, 2015). Greens et al. (2014) provides a detailed derivation of the KVA.

Another valuation adjustment is the funding value adjustment (FVA). FVA arises when the cost of funding the hedge of an uncollateralized derivative is different from the risk free rate. There is an ongoing discussion among scholars on whether the valuation adjustment should even be considered, known in academia as the FVA debate. FVA potentially double counts DVA and according to some authors it should not be recognized in a rational trading decision. See Hull and White (2012), Burgard and Kjaer (2012) and Andersen et al. (2016).

CVA and DVA in the Literature and Practice

Calculating CVA and DVA

Below follows a general derivation of the CVA component for a derivative that at all times is of zero or positive value to its holder, B. Any payments under the derivative contract are contingent on the survival of the derivative issuer, C. The value of the contract under the assumption that no default can occur is *f*. At any time *t* between 0 and *T*, where *T* is the maturity of the contract, the present value at time 0 of the realized cash flows of the contract is $f(0,t)$. The value of the remainder of the contact discounted back to time 0 is $f(t,T)$. There is no collateral posted. From the perspective of the derivative holder there are two general situations that can occur:

- Counterparty C honors all payments under the contract and the holder recognizes the full value *f*.
- Counterparty C defaults at time τ and the value for the holder is $f(0,\tau)$ plus what can be recovered from $f(\tau,T)$. The ratio of what can be recovered is referred to as RR_C.

For the holder the value of the transaction, *V*, at time 0 is given by,

$$V = [\mathbb{1}_{\{\tau>T\}} f + \mathbb{1}_{\{\tau<T\}} (f(0,\tau) + RR_C\, f(\tau,T))]$$

Where $\mathbb{1}_{\{\tau>T\}}$ is an indicator function which takes the value 1 if the default does not happen during the time period of the derivative contract and vice versa for the second indicator function in the formula. This gives that the first term is the expectation of complete fulfilment of the contract, i.e. no default. The second term hold both the realized value of the derivative up until the default and the value of what is expected to be recovered for the holder in the case that the counterparty will default.

Since we have that,

$$f = f(0,T) = f(0,\tau) + f(\tau,T)$$

The formula can be rearranged to,

$$V = [\mathbb{1}_{\{\tau>T\}} f + \mathbb{1}_{\{\tau<T\}} (f - f(\tau,T) + RR_C\, f(\tau,T))]$$

$$= [\mathbb{1}_{\{\tau>T\}} f + \mathbb{1}_{\{\tau<T\}} f + {}_{\{\tau<T\}}(RR_C\, f(\tau,T) - f(\tau,T))]$$

$$= f - [\mathbb{1}_{\{\tau<T\}}((1 - RR_C\,)\, f(\tau,T))]$$

As describe earlier, when taking default risk into account in the valuation, the value can be described as the no-default value less the CVA. In the general case with no collateral posting and one-sided default risk, we have,

$$\text{CVA} = [\mathbb{1}_{\{\tau<T\}}((1 - RR_C)\, f(\tau,T))]$$

One can include the presence of collateral by simply adding a collateral term that represents the level of collateral posted,

$$\text{CVA}_{\text{COLL}} = [\mathbb{1}_{\{\tau<T\}}((1 - RR_C)\, (f(\tau,T) - COLL(\tau)))]$$

Gregory (2009) shows that for a transaction with bilateral default risk, positive and negative values of f and no collateralization the value of the transaction can be described as,

$$V = f - \mathbb{E}\left[\mathbb{1}_{\{\tau^l<T\}}\begin{pmatrix} \mathbb{1}_{\{\tau^l=\tau_C\}}(1 - RR_C)\, f(\tau^l,T)^+ + \\ \mathbb{1}_{\{\tau^l=\tau_B\}}(1 - RR_B)\, f(\tau^l,T)^- + \\ \mathbb{1}_{\{\tau^l=\tau_B=\tau_C\}}(f(\tau^l,T) - RR_C f(\tau^l,T)^+ - RR_B f(\tau^l,T)^-) \end{pmatrix}\right]$$

Where,

τ_C is the default time of part C,

τ_B is the default time of part B,

τ^l is the first occurring default of the above,

RR_C is the recovery rate of part C,

RR_B is the recovery rate of part B,

$f(\tau^l,T)^+$ is the maximum of $f(\tau^l,T)$ and 0,

$f(\tau^l,T)^-$ is the minimum of $f(\tau^l,T)$ and 0

As seen from part B the first term within the brackets corresponds to the CVA, the second the DVA. The third term within the brackets represents the case where both parties default simultaneously. In practice, the probability for this event is considered negligible. (Ruiz, 2015)

A General CVA model

Kjaer (2011) assumes a simple model for defaults to extend the CVA equations into a CVA model. Both parties in the case with bilateral credit risk are assumed to have default intensities, λ_B and λ_C. This means that during a time period with the length *dt* the default probability of part B defaulting is $\lambda_B\, dt$. Correspondingly, the probability of part B's survival at time 0 up to time t is given by,

$$S_B = e^{\int_0^t \lambda_B du}$$

Furthermore, the recovery rates are assumed to be deterministic. The CVA and DVA for bilateral credit risk is then given by,

$$CVA(t) = (1 - RR_C) \int_t^T f^+ \lambda_C S_C S_B du$$

$$DVA(t) = (1 - RR_B) \int_t^T f^- \lambda_B S_B S_C du$$

Where f^+ and f^- are the present values of the positive and negative expected average exposures[8] respectively. Here it becomes apparent that the drivers in CVA and DVA are the exposures in the derivative and the changes in riskiness of the counterparties. In the case with unilateral default risk the CVA becomes,

$$CVA(t) = (1 - RR_C) \int_t^T f^+ \lambda_C S_C du$$

Here as well it is clear how a larger value of the derivative will increase CVA together with the riskiness of the counterpart. It should also be noted that both CVA and DVA decreases with time.

A CVA Framework – Two Stylized Cases

Given the discussion above, there are many aspects to take into account when considering the balance sheet value of a derivative. However, in theory, one could consider a "perfect" CSA agreement that sets the exposure at all times to zero. In the notation used above,

$$COLL(t) = f(t,T)$$

[8] The sum of the positive and negative exposures should equal f according to Ruiz (2015).

Furthermore, if the interest rate on the collateral is the same as the risk free rate, the CRA term will have no value. (Hull and White, 2014)

Perfect collateral posting is only hypothetical. However, many banks today have CVA desks that collects the CVA exposures from the other trading desks, so that they are left with only the no-default derivative, the typical setup is illustrated in Figure III. Whether it is done by a theoretically perfect CSA or hedged with a CVA desk, many trading desks today have no exposure to CVA and can therefore continue to discount their trades with OIS rates. (Ruiz, 2009)

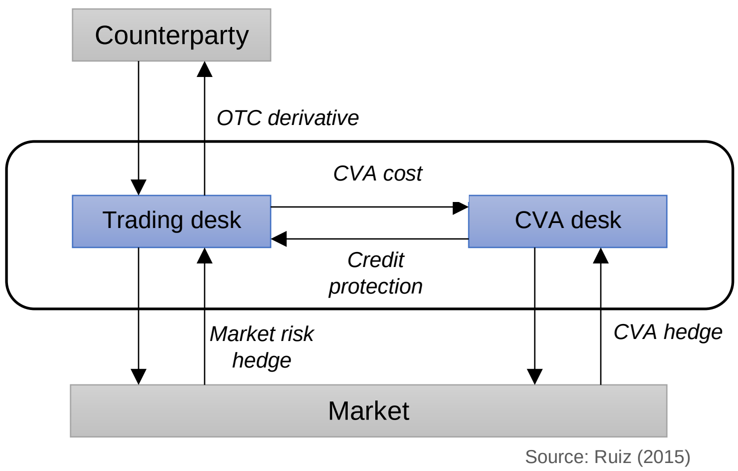


Figure III: The role of a CVA desk and a traditional trading desk at a bank

Hull and White (1995, 2014) presents a model for simplified calculation of CVA when the default risk is unilateral and no collateral is posted. For a derivative with payment and maturity at T and no-default value f, the function $w(T)$ is defined so that if the risky counterparty C defaults before T $w = RR_C$ or else $w = 1$. This is illustrated with two zero coupon bonds with maturity T. The first bond being default free, denoted B_{rf},, and the other contingent on the survival of C, denoted B_C. The price of the two bonds at time 0 is defined as,

$$B_{rf} = \mathbb{E}\left(e^{-\int_0^T r\,dt}\right)$$

and,

$$B_C = \mathbb{E}\left(e^{-\int_0^T r\,dt}\, w(T)\right)$$

Where r is the risk free rate. Each bond has a yield, where the yield of the risk free bond is r and the risky bond's yield is denoted y.

Under the assumption that *w(T)* is the same for the risky zero coupon bond as for a derivative issued by C, the value taking into account the default risk of the derivative is given by,

$$V = \mathbb{E}\left(e^{-\int_0^{\tau} r\,dt}\, w(T) f_{\tau}\right)$$

Where τ is the first occurring time of a default and maturity and f_{τ} the value of the derivative at the time of τ. Since the value of the derivative at time τ, without the presence of default risk, must be the discounted value of its value at *T*,

$$f_{\tau} = \mathbb{E}\left(e^{-\int_{\tau}^{T} r\,dt}\, f_{\mathrm{T}}\right)$$

We can expand the value of the risky derivative to,

$$V = \mathbb{E}\left(e^{-\int_0^{T} r\,dt}\, w(T) f_{\mathrm{T}}\right)$$

Hull and White goes on to assume that the variables determining *w(T)* are independent from those determining *r* and *f*. This has the implication that *w(T)* can be moved outside the expectation and we have that,

$$B_C = w(T)\, \mathbb{E}\left(e^{-\int_0^{T} r\,dt}\right)$$

and

$$V = w(T)\, \mathbb{E}\left(e^{-\int_0^{T} r\,dt}\, f_{\mathrm{T}}\right)$$

Substituting and considering that the yield on the respective bonds are *r* and *y*, the resulting value is,

$$V = e^{-(y-r)(T-0)} f$$

Analogously from before, the CVA can be defined as a term subtracted from the no-fault value (Hull and White, 2014),

$$CVA = f e^{-(y-r)(T-0)} - f$$

In this specific case the CVA can be obtained by simply discounting the derivative with the risky counterparty yield and subtracting the no default value of the same derivative.

Managing CVA and DVA

So far the xVA calculations has been motivated with the changed market conditions and increased regulatory scrutiny after the crisis. In the previous section CVA/DVA models have also been examined. In this section, some of the vast literature on the management of counterparty credit risk is examined.

Zhu and Pykhtin (2007) compares the credit risk in the OTC derivative business with the credit risk that banks traditionally have managed on their loan portfolios. The authors highlight two important differences. The first is the bilateral nature of the credit risk in the derivative trades. The credit risk might be to one of the parties' advantage at the inception of the trade, however during the life time of the contract the credit risk might change in the opposite direction. Second, the exposure in derivative is far more uncertain than in a loan. Generally a derivative can go from positive to negative exposure during its life time, unless it is a one-sided derivative such as a call option. This is why the xVA is a new perspective for the banks and it is important for banks to be able to model the exposure correctly. Otherwise the bank will not be able to manage its risk properly. The authors note risk mitigating actions such as setting credit limits and pricing and hedging the risks.

Moser (2014) points out that the CVA and DVA are not measures of risk exposure towards a derivatives counterparty. Rather they represent the price of the counterparty credit risk in the specific transaction or portfolio. The consequence is that the CVA and DVA fits into the risk neutral market valuation framework of the banks traditional derivative business. It should therefore be hedgeable as any other risk. This stands in contrast with the pre-crisis actuarial view of carrying reserves for covering credit losses, a view often backed up with historical data on defaults, which does not focus on the deterioration of credit quality as a source of loss.

From the above and as described by Ruiz (2015), it follows that in practice the objective of a CVA desk would be to focus on minimizing counterparty risk Value-at-Risk and P/L volatility given the internal and external market constraints. Ruiz also points out the distinction between hedging defaults and hedging CVA as important in the banks risk management. In order to be able to do so, banks must invest in models so that they are able to measure the risks correctly. When one is able to measure the risk, it is usually very expensive and in some cases impossible to completely hedge out all risk. Consequently, banks tend to hedge out the main exposures where hedging instruments that have low transaction costs and are liquid exists.

There are many suggested models for calculating CVA in general, see Assefa et al. (2011) for a summary. There are also many attempts at quantifying CVA for many different financial instruments. For example Brigo and Chourdakis (2009) focus on Credit Default Swaps (CDS) and Brigo et al. (2010) calculates CVA for interest rate derivatives.

Hedging DVA is however a subject with little academic exposure. The issue that have received attention is that a derivative issuer cannot perfectly hedge its own default risk. Castagna (2012) argues that an entity can easily sell short its own bond, in fact that is what each debt issuer does. However, it is not possible for the issuer to “go long” its own credit spread. While the issuer in theory could enter a fictitious CDS contract on itself as suggested by Gunnesson and Fernández (2014), it would not work in practice. This would mean that if one where to hedge the DVA in practice, perfect replication would not be possible and other hedging strategies would need to be considered.

Structured Notes

As mentioned earlier banks today usually have either a CVA desk or they handle the CVA exposure at a trading desk level. In the rest of the paper the xVA challenges of a structured notes desk will be considered. Below follows an introduction to the structured notes market.

A structured note or Structured Product is a general term for financial instruments offered by an issuer with a pay-off strategy dependent on one or more underlying assets. The European Structured Investment Products Association (EUSIPA), which is an organization for structured notes issuers within Europe, makes a general categorization into two main types of products, see Figure IV. The products in scope in this thesis are Investment Products which usually corresponds to bonds sold to investors, while Leveraged Products are usually sold in the form of warrants or certificates. (EUSIPA, 2016)

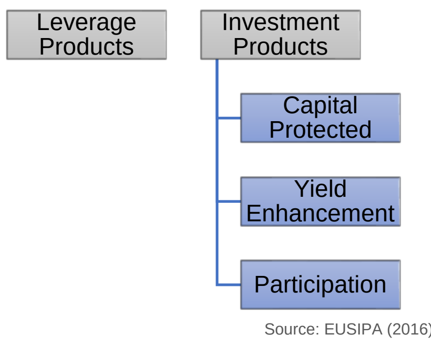


Figure IV: EUSIPA categorization of Structured Products

The first structured products started selling in the 1980s, but it was not until beginning of the 2000s the instruments became popular as a product for retail investors. The structured product market peaked in 2007 with European sales reaching 250 billion Euro (Sokolowska, 2015). In the years following the crisis the sales volumes have more than halved (SRP, 2015).

The traditional purpose of the structured notes desk at a bank is to hedge the cash flows of the issued products. With the emergence of xVA the structured notes desk will have new challenges. First we consider the most common pay-off structures of structured notes and their building blocks. Then the balance sheet of an issuer is considered and the impact of xVA will be discussed.

Pay-off types

The type case of a structured note is the capital guaranteed equity linked note. The investor buys a bond from the issuer where the investor is guaranteed to receive the principal amount of the note at the maturity. In addition, the note includes an embedded call option with an asset or basket of assets as underlying with the same maturity as the bond. This note can be thought of as having two components. When the investor buy the product he or she pays the principal amount to the issuer. In turn, the issuer creates a zero coupon bond on its balance sheet. The zero coupon bond will pay out the principal amount at the maturity of the note and its value at inception would be the discounted value of the principal amount. The difference between the current value of the zero coupon bond and the principal amount paid by the investor is used to buy call options.[9] At the maturity the investor will receive the pay out from the zero coupon bond that equals the invested amount, plus the payoff from the embedded derivative.

In the case described above, the embedded option is usually bought at-the-money and the payoff is leveraged towards the underlying performance. This leverage can be both above and below 100%. The variations for structuring investment products are endless. For example, the capital invested in the note can be partially or fully at risk, or an additional short out-of-the money call can be embedded in the note so that the pay-off of the note is limited. The purpose is in both cases to increase the note's leverage towards the underlying performance. Furthermore, the option could be either composite or quanto, the difference is described in Table I and in further detail in the Methodology section.

Another common product type is the autocallable note. This type of note pays out coupons dependent on the performance of the underlying instruments compared to pre-defined barrier levels. They also have a callable feature that is triggered when all underlying separately or as an average are above their strike levels. The bond is then early redeemed and the investor receives the principal amount plus a coupon before the legal maturity of the note. The investor is exposed to the negative performance of the underlying instruments at the maturity of the note and risk losing parts of the invested capital if the underlying have performed worse than a pre-defined level.

[9] This is not always the case. Low funding spreads and negative interest rate can make the amount of money available for buying very small or even negative. This can be solved by setting the initial price of the bond above the principal of the zero coupon bond. The investor is not guaranteed to receive difference between the price and the principal of the zero coupon bond at maturity, but this amount can be used to buy options at the inception of the product. This is usually referred to as selling the note above par.

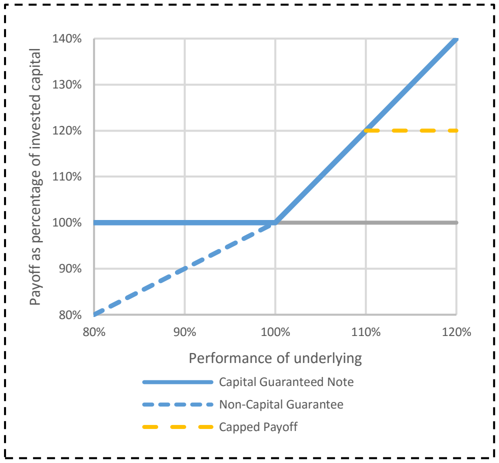
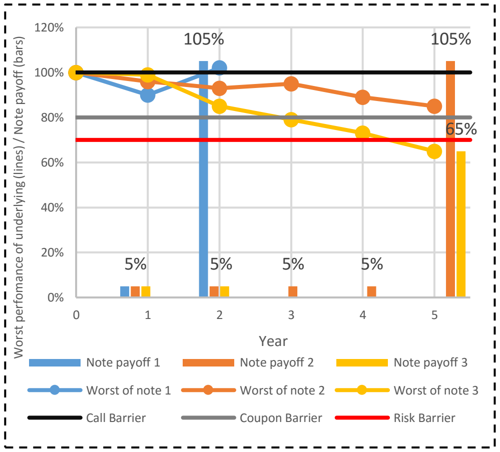
Table I describes the embedded options in more detail and presents their variations. The payoff formulas for the respective notes are also illustrated.

Table I: Description of Common Payoffs for Structured Notes

This table describes the most common payoff types for embedded options in structured notes as well as the type of underlying and other common features The figures in the table illustrate the payoff functions when the options are embedded in a note format.

<table>
<tr><th>Underlying</th><th>Type</th><th>Payoff description</th><th>Other features and variations</th><th>Example payoff embedded in note[ab]</th></tr>
<tr><td rowspan="3">● Basket of stocks
● Single stock
● Index</td><td>Quanto option</td><td>The largest of the price of the underlying at maturity less the strike and the defined minimum pay-out (usually 0). If there are several underlying the basket performance is equal to the sum of each instruments performance times its weight.</td><td rowspan="2">● Leverage on positive payoff

● Cap on positive payoff

● Asian (average value) points, rather than looking at the performance of the underlying from strike date to maturity date, the value of the underlying at maturity is the average of its value at a number of predetermined dates.</td><td rowspan="2">
</td></tr>
<tr><td>Compo option</td><td>Same as quanto option, however, the performance considered is the performance of the underlying is multiplied with the performance of the predefined exchange rate during the life time of the option.</td></tr>
<tr><td>Autocallable</td><td>At a given frequency the performance of the underlying since the start of the option is considered. If the worst performing, or in some cases the average, of the underlying's is above a predetermined "call barrier" the option will redeem and pay out a coupon. In some cases there also exists a second lower barrier for just paying out coupons. If the option is not redeemed it lives on to the next date and eventually the maturity date. If the performance at maturity is below a predetermined risk barrier the buyer will have to pay the negative performance to the seller.</td><td></td><td>
</td></tr>
</table>

[a] The example payoff for the embedded quanto and compo options has a leverage on the positive payoff of 200%. The cap is applied when the positive payoff reaches 20%.

[b] The example payoff for the autocallable has a coupon of 5%. The drawn lines represent the worst performing of each notes underlyings. Note 1 is terminated in year 2 as the worst performing underlying is above the call barrier. Note 3 only repays 65% of the initial capital as the worst perforing underlying is below the risk barrier at the maturity of the note.

Structured Notes on the Balance Sheet

On the balance sheet of the issuer the structured notes will subject to xVA. In the following section, the balance sheet of a single structured note is examined and the effects from considering default risk in its components are assessed. While the components might have other effects on the global balance sheet of the bank, the balance sheet of the structured notes desk is here considered in isolation.

For the structured notes desk, the bond will be a liability and the components used to hedge the note assets. Accounting for the no-default value of the components, the balance sheet of a perfectly hedged structured note would balance according to below:

A	L
ZCB	Bond
D	- ZCB
	- D

Where D, denotes the derivative and ZCB, the zero coupon bond.

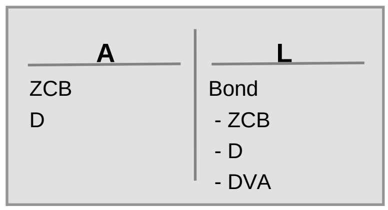
The next step would be to account for credit risk. The structured note is evidently not default free. Therefore the cash flows of the note should be discounted with the credit spread of the issuer. However, let's consider each component separately, starting with the zero coupon bond.

The ZCB as a hedge will be done with the treasury of the issuer. The ZCB component on the asset side contains the same default risk as the ZCB component on the liability side, since both are contingent on the survival of the issuer. Therefore their values should be equal on both sides of the balance sheet. Since it is common practice to include default risk in bond valuations, there should be no need to add any adjustments to the balance sheet. It should also be noted that this credit risk is unilateral, the issuer is unaffected by the default of the holder of the bond.

For the derivative components, the components on the asset side and the liability side will be different in terms of default risk. The asset side holds an OTC derivative, generally subject to a bilateral CSA. From the earlier discussions it has been pointed out that under certain assumptions, a collateralized OTC derivative can be considered on the balance sheet at its no-default value. Hence there should be no valuation adjustment terms added on the asset side. However, on the liability side the derivative is embedded in the structured note. This makes it similar to an uncollateralized OTC derivative. As part of the note the embedded derivative would contain the same default risk as the ZCB. It would therefore be required that the no-default value is adjusted with the cost of the issuer default risk. From earlier we have that the accounted value of the derivative is equal to the no-default value less the unilateral CVA. Applying this analogously for the DVA and rearranging we have that,

$$V_L = f + DVA$$

The balance sheet can then be described as,



This means that, under the assumptions presented above, out of the xVAs related to counterparty credit risk only the DVA of the embedded derivative is added. This is true regardless whether the DVA is a positive or negative term, since the exposure of the bond is only in one direction.

The effect for the structured notes desk is that the DVA needs to be considered on its balance sheet and thereby the P/L of the desk has a new source of volatility. Throughout the rest of the thesis, the components of a structured notes portfolio of a Nordic issuer is replicated so that the historic DVA can be calculated. Based on the behavior of the DVA, hedge strategies are formulated with the purpose of minimizing the volatility of the DVA and thereby the P/L of the structured notes desk.

Data

Below follows a description of the data. The data used in the valuation and hedging is collected and derived from Bloomberg data. Data on the structured notes is obtained from the issuer.

Description of Structured Notes Portfolio

The portfolio of structured note is the portfolio of the issuer that holds the liabilities in the form of the issued debt and the assets that is used to cash flow hedge the liability. Our focus is the derivative part of this portfolio.

The sample portfolio includes notes issued during the period January 2009 to July 2016, in total 1165 products. The issues were sold in all Nordic countries and in five currencies, Danish Krone (DKK), Euro (EUR), Norwegian Krone (NOK), Swedish Krona (SEK) and US Dollars (USD). All notes have underlying equity assets, including single stocks, baskets of stocks or stock indices.

Table II provides a summary of the data of the structured notes portfolio. The general theme since the first year is that the diversification among the issues seems to increase in terms of product type, currency and term. The number of issues clearly peaks in 2013 with 235 issued products.

The ratio of notes with partial or no capital guarantee increases throughout the years. An interesting observation from a DVA perspective. The embedded derivative of a principal protected notes is a call option that cannot take a value below 0 and thereby negative DVA. While in the case with the non-capital protected notes the embedded derivative can have a negative DVA.

Table II: Summary of Data on Structured Notes Sample Portfolio

This table presents a summary of the data on the yearly issues in the structured notes sample portfolio between 2009 and 2016 (until July). The total number of issued notes in the sample is 1,165.

	Year							
	2009	2010	2011	2012	2013	2014	2015	2016
Structure Type								
Autocallable	4	20	20	80	82	64	59	27
Composite	0	0	20	32	75	68	43	23
Quanto	78	92	67	58	78	68	60	47
Capital Guarantee								
Full	64	82	81	78	105	97	77	56
Partial	1	3	1	0	20	9	7	7
None	17	27	25	92	110	94	78	34
Currency								
DKK	1	3	8	2	2	5	5	0
EUR	39	47	43	48	53	46	40	30
NOK	2	0	2	4	3	10	8	7
SEK	40	62	54	116	163	115	83	45
USD	0	0	0	0	14	24	26	15
Other Statistics								
Average Maturity [a]	4,00	4,09	3,99	4,45	4,64	4,96	5,03	4,90
Standard Deviation Maturity [a]	0,78	0,73	0,96	0,78	0,91	0,82	1,07	1,23
Average Number of Underlying	6,51	6,81	5,97	6,03	4,67	4,14	5,38	6,94
Standard Deviation Underlying	4,33	4,70	4,59	3,87	3,70	3,55	3,87	3,83
Average Size [b]	10,90	9,37	11,16	6,53	5,58	5,36	6,70	4,25
Standard Deviation Size [b]	8,57	16,13	15,96	9,97	8,80	6,57	8,37	3,97
Total number of notes	82	112	107	170	235	200	162	97

[a] Number of years

[b] The size is presented in millions of Euro.

Input Parameters for Valuation

In total there are 610 unique assets that occur as underlying in the products of the sample portfolio. These assets and their statistics are used for the historic valuation of the structured notes portfolio. The choice of input parameters is essential for the valuation to be reliable. Therefore, all of the data has been fetched from Bloomberg which is a data source that many practitioners and academics use for market data.

The data on the underlying instruments is daily, except for the calculated correlation matrices which is done on a monthly basis. Apart from the data on the underlying assets, foreign exchange rates are also part of the dataset as these are used when valuing compo options. The underlying instruments are denoted in 17 different currencies and since there are five issuing currencies there are a total of 80 currency pairs to consider. For both currency and equity fixings the closing end of day fixings have been collected.

For the risk free rates OIS rates have been used when they exist. In NOK there exists no OIS market (Norges Bank, 2014), and for SEK and DKK the data prior to 2011 is poor and not existing for periods. Therefore, the respective LIBOR swap rate curve has been used as a substitute where necessary, a practice suggested by Hull and White (2013). The curve points of the interest rate data are overnight, 3 month, 1, 3, 5, 7 and 10 year. For the borrowing spread of the issuer, the issuer's CDS curve has been used as a proxy.

The dividend assumptions used in the valuation has been the total dividends paid out in the last 12 months of the asset in question. This is captured in the Bloomberg field EQY_DVD_YLD_12M. For volatilities, the market implied volatility has been used. However, for some assets, the option markets are not liquid enough for reliable data or simply not existing. In those cases a GARCH(1,1) model[10] has been fitted to the historical data to calculate the volatility of the asset used in the valuation. Figlewski (2012) uses GARCH models to explain risk neutral volatility with good results.

[10] Generalized autoregressive conditional heteroscedasticity (GARCH) first presented by Bollerslev (1986) is a form of Autoregressive conditional heteroscedasticity (ARCH) model where an autoregressive moving average model (ARMA) is assumed for the error variance. ARCH was first presented by Engle (1982) who later received Nobel Prize in Economics for his works.

Methodology

In this section the structured notes portfolio of a Nordic issuer of structured notes is considered. In order to replicate the DVA of the portfolio, the embedded derivatives in the structured notes are valued for a historic time period. The valuation is done by Monte Carlo simulation and from the value of the derivatives the DVA is derived by discounting the cash flows under the derivatives with the issuer's borrowing cost as suggested by Hull and White (2014).

Unfortunately, the convenient Black and Scholes option valuation model cannot be used when valuing exotic options. A popular alternative approach is Monte Carlo (MC) simulation, first brought forward by Phelim Boyle (1976). In general, the MC approach evaluates the expectation of an option payoff in two steps. First, the underlying asset prices are repeatedly simulated over the time period applicable for the option payoff. The number of simulations needs to be large and each simulated path based on a random seed. In the second step, the option payoff of each individual path is considered. The average of the payoffs is then discounted to present time and the resulting value is regarded as the value of the option instrument. The drawback of the MC method is that for complex problems the precision in the result is low. The solution is to increase the number of simulations, however this causes the MC approach to consume both computational power and time. (Boyle et al., 1997) For the purposes of this analysis, the MC approach is well suited as it offers a convenient way of solving numerous complex pricing problems.

Next the modelling of asset prices is described. Then follows the methodology of calculating DVA on portfolio level and the description of hedging strategies applied for hedging DVA in the portfolio.

Simulation of Asset Prices

A basic assumption in derivative pricing is that the changes in the price of an asset follows a geometric Brownian motion,

$$dS = \mu S dt + \sigma S dz$$

Where S is the price of the relevant asset, μ the expected return, dt the distance in time between the start of the assumed period and the end of it, σ the volatility of S and dz a so called Wiener process. A Wiener process is a stochastic process in continuous time, in other words a way to describe a development over time where each increment in time is infinitely small. (Hull, 2009)

The process for the price of asset S in its domestic currency, Y, is assumed to be the geometric Brownian motion described above. For a derivative on asset S denominated in another currency, X, the same process cannot be used. A call option denominated in X on asset S denominated in currency Y will have a pay-off equal to the maximum of $S_T Q_T - K$ and 0 where S_T is the price of S at maturity of the option, Q_T the exchange rate expressed as the number of X per Y and K the strike price of the option.

Furthermore, we assume that Q itself follows a risk-neutral geometric Brownian motion stemming from the no-arbitrage assumption of the interest rate parity,

$$dQ = (r_x - r_y) Q dt + \sigma Q dz$$

We set the expected return for S, μ, to the risk free rate less a dividend yield that is assumed to be continuous, g, and get the risk-neutral,

$$dS = (r_y - g) S dt + \sigma S dz$$

When considering $f(SQ)$ as a function from here on called F, one can by application of Itô's lemma (Itô, 1944) find that the process for F is,

$$dF = (r_x - g) F dt + \sigma_F F dz$$

De Weert (2011) shows that the variance of F is equal to,

$$\sigma_F^2 = \sigma_S^2 + 2\rho\sigma_S\sigma_Q + \sigma_Q^2$$

Another common type of option that is similar to the composite option is the quanto option. The difference from the composite option is that the exchange fixed at the inception of the option, usually at 1. This means that the option would pay out as if the asset was denominated in the same currency as the option. In a similar manner as before, the process for when *S* denominated in another currency can be shown to follow,

$$dS = (r_y - g - q)Sdt + \sigma Sdz$$

Where *q* is commonly referred to as the quanto drift adjustment (Wystup, 2007),

$$q = \rho \sigma_S \sigma_Q$$

Since each asset price simulation has its own Wiener process, the outcome will be different across time as well as across assets. However, it is not the case in reality that changes in asset prices are completely independent. At each point in time there is a correlation between the movements across assets.

In order to take the correlation structure into account when simulating asset prices, there exists several methods. A common method to model dependency properties among variables is Cholesky decomposition. However, while Cholesky is usually the preferred method, there are instances where it cannot be used. (Gilli et al., 2011) As a great number of correlation transformations will be done in this analysis, and it is difficult to guarantee that the Cholesky decomposition can be used in each instance, the correlation will instead be modeled with Eigen decomposition. Eigen decomposition is more stable than Cholesky decomposition while not as fast (ETH Zürich, 2015).

Portfolio Valuation and DVA Calculations

The embedded derivatives of the entire structured note portfolio are valued on a monthly basis in the Monte Carlo framework. The net present value (NPV) of each embedded derivative outstanding at time *t* is simulated. From the value of each derivative the DVA is calculated according to Hull and White (2014). As the structured note is always a liability for the issuer the DVA calculation for the DVA of each product *j* at time *t* is simplified to,

$$DVA_{j,t} = \sum_{i \in T} f_i e^{-t(r_{B,c,t,i} - r_{c,t,i})} - f_i$$

Where

f_i is the NPV at *t* of payment *i* in the embedded derivative,

$r_{B,c,t,i}$ is the issuer's borrowing rate at time *t* with the maturity at occurrence of *i* in currency *c*,

$r_{c,t,i}$ is the risk-free (OIS) rate in currency *c* between *t* and the payment *i*,

and *T* is the set of differences in time between time *t* and the occurrence of payment *i*.

For each point in time *t*, the total DVA of the portfolio is,

$$DVA_{p,t} = \sum_{j=1}^{n} DVA_{j,t}$$

Hedging DVA on a Portfolio Level

Hedging Assets

The first step in setting up hedging strategies for the DVA in the structured notes portfolio is to identify and select appropriate hedging assets. There exists a wide range of different hedging instruments that can be utilized. When considering suitable instruments it is important to note that the structured notes portfolio is diversified, both in terms of geographic exposure and pay-off types. Hedging each individual underlying would be very costly, both due to the vast number of different assets and the problem with low liquidity in certain names. Consequently, liquidity and coverage are important features of the hedging assets.

Three different instrument types will be considered,

- Future contracts
- Put options
- Standardized CDS contracts

And four different underlying,

- EURO STOXX 50
- S&P 500
- Kospi 200
- Markit Itraxx Europe Crossover (Xover)

The EURO STOXX 50 consists of 50 of the largest and most liquid stocks in 11 Eurozone countries. This would give the investor exposure to almost 60% of the market capitalization in the 11 countries (Morningstar, 2010). In addition, the future is one of the most traded instruments on Eurex (Eurex, 2016). The S&P 500 index consists of 500 large companies traded on New York Stock Exchange or NASDAQ in the US. The Kospi 200 is an index which consists of 200 large companies from Korea Exchange's Stock Market Division in South Korea. The Markit Itraxx Europe Crossover is a CDS index consisting of 75 European high yield rated corporate CDS and is one of the most liquid CDS indices traded. The index is updated with a new version every 6 months, where constituents that do not fulfil the criterions for being in the index are replaced with new names (Eisler and Bouchaud, 2016). Only the most recent versions of the index will be used in the analysis.

The future contracts rolls on a quarterly basis and only the contract closest to maturity at each point in time is considered in this analysis. The data for these instruments is exchange data fetched from Bloomberg. Due to lack of data on options, the options used for hedging will be valued with the Black and Scholes formula (1973). This has the drawback that transaction costs (bid-offer spread) cannot be assessed. The CDS contracts are traded OTC, but the bid and offer levels are available in Bloomberg.

Hedge Strategies

The aim of the hedge strategies is to neutralize, or at least reduce, the monthly changes in the DVA excluding the DVA from new transactions. The issuing bank has an outstanding portfolio of cash flow hedged structured notes with a known DVA at time 0. Based on the historic relationship between the changes in the DVA and the respective hedging instrument, the bank will each month enter a position in the hedging instrument that during the holding period is expected to neutralize the DVA change.

Since the total DVA of the portfolio is the net of both negative and positive DVA, it ranges from values close to 0 to larger both negative and positive quantities. In order to calculate a percentage return that can be compared with the hedging assets, the absolute value of the total DVA is considered as the base and the change in DVA between *t* and *t*-1 is cleared from DVA arising from new transactions, so that only the changes from the NPV fluctuations of the embedded derivatives and the changes in the issuer's credit risk are considered.

To be able to hedge the fluctuations in the DVA of the portfolio, hedge ratios will be determined with the help of OLS regressions.[11] The general specification of the OLS regression model used for determining the hedge ratios at time *t* is,

$$(\Delta DVA_t/DVA_{t-1}) = \alpha_t + (\Delta H_t/H_{t-1})\beta_t + \varepsilon_t$$

Where the dependent variable $\Delta DVA_t/DVA_{t-1}$ is the percentage change in DVA as described above for period $t-1$ to t, α_t a constant, ΔH_t the percentage return for the respective hedging asset in the period $t-1$ to t, β_t the factor for the hedging asset and ε_t an error term.

[11] Hedge ratios are frequently used in commodity trading. The strategy was girst presented by Johnson (1960). Daigler (1998) applies hedge ratios for bonds.

The regression analysis is conducted on a monthly basis with monthly data. The analysis is done with input from a rolling window between t-12 and t. The hedge position at time *t* is calculated as the hedge ratio at time *t* multiplied with the position of the absolute DVA at time *t*. The position in the hedging asset is bought or sold with the opposite sign of the hedge ratio calculated at time *t* and held to *t*+1 when it is rebalanced. This is done on a monthly basis. If the return on the unhedged portfolio in period *t* to *t*+1 is ΔDVA_{t+1}, then the return of the hedged portfolio

$$\Delta DVA_{t+1} - \beta_t \, DVA_{ABS,t} \, (\Delta H_{t+1}/H_t)$$

For a hedge to be successful the volatility of the hedged portfolio return should be lower than the unhedged portfolio return.

In total five different hedges are considered,

- CDS Hedge
- Equity Future Hedge Single
- Equity Future Hedge Basket
- Equity Option Hedge Single
- Equity Option Hedge Basket

The CDS hedge would aim at capturing the changes in the DVA stemming from the changes in the credit risk of the issuer. The CDS contracts in scope are standardized CDS contracts on Markit Itraxx Europe Crossover.

The first future hedge utilizes EURO STOXX 50 futures. The equity futures are selected to capture the changes in DVA arising from changing market levels in the underlying instruments of the structured notes. If the global markets are not correlated, this first strategy will not work. Therefore a second future strategy is defined with the focus of global diversification. The second future strategy is similar to the first strategy with the only difference that the total DVA is divided into different sub-portfolios based on the region of the underlying instruments of the derivatives the DVA stems from. The regression analysis is then done on the sub-portfolios with exposures towards Asia, Europe and America with the returns of Kospi 200, EURO STOXX 50 and S&P 500 futures contracts respectively. The strategy is then applied to each sub-portfolio and the remaining parts of the portfolio are left unhedged.

The option strategies are similar to the future strategies. The difference is that in these strategies out-of-the-money put options are used for the same underlying. This type of options are used for two reasons, firstly they provide down-side protection when the market drops. Secondly the out-of-moneyness of the options implies a low premium. The strike is set to 105% of the spot value at the inception of the option. The options have a term of 3 months when they are bought and the returns are realized each month when the trade is rebalanced. In the first version of the options strategy EURO STOXX 50 options are considered. In a second version a basket of Kospi 200, EURO STOXX 50 and S&P 500 options are used based on the region weight in the total DVA number. The hedge ratios are first implemented on the sample period 31st January 2009 to 31st July 2015. The period 31st August 2015 to 31st July 2016 is considered the out of sample period where the strategies soundness are tested.

Results

Portfolio DVA

The DVA of the sample portfolio is calculated in EUR on a monthly basis and the results are shown in Figure V. The positive and negative DVA nets out on a portfolio level but are presented separately in Figure V together with the inverted 5 year CDS spread of the issuer which illustrates how the DVA changes with the credit risk of the issuer. The average DVA of the portfolio is 2.6 million EUR and the standard deviation of the DVA 3.0 million EUR during the full period. During the first years of the sample period the bank issued mostly capital guaranteed notes. The embedded options in these notes can never take a value below 0. This means that for the beginning of the sample period there is none or very little negative DVA. As the non-principal protected notes are issued it can be seen that also the negative DVA increases.

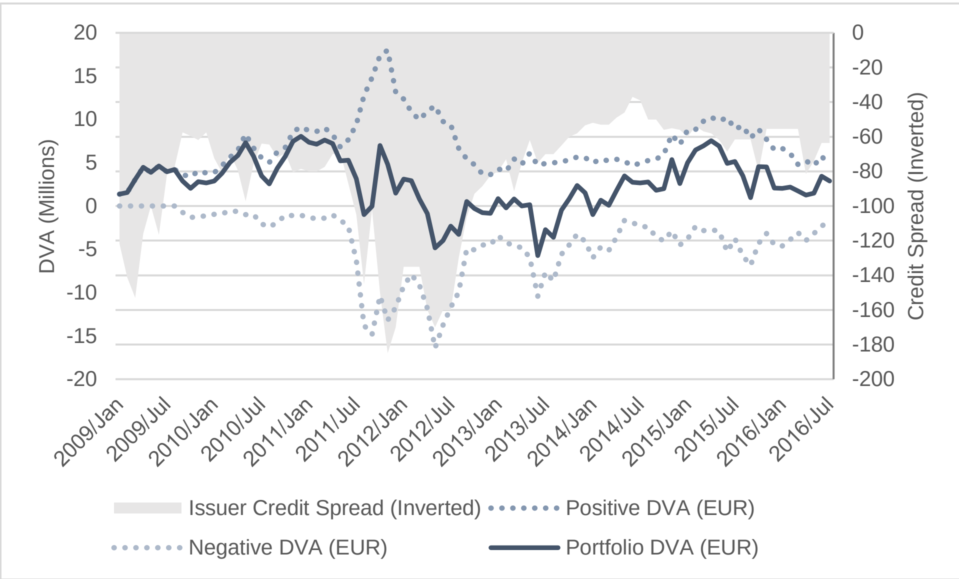


Figure V: Total DVA of the sample portfolio from 2009 to 2016
The figure illustrates the total net DVA and the total positive and negative DVA of the portfolio. The inverted credit spread of the issuer over the period is shown in the background.

The DVA is compared to the EURO STOXX 50 index and the Markit Itraxx Europe Crossover spread over the sample period in Figure VI and Figure VII respectively. The credit spread has been inverted to reflect that lower spread implies less risk. The figures shows a tendency for co-movement in the portfolio DVA and the asset prices. Nonetheless, the DVA is far more volatile.

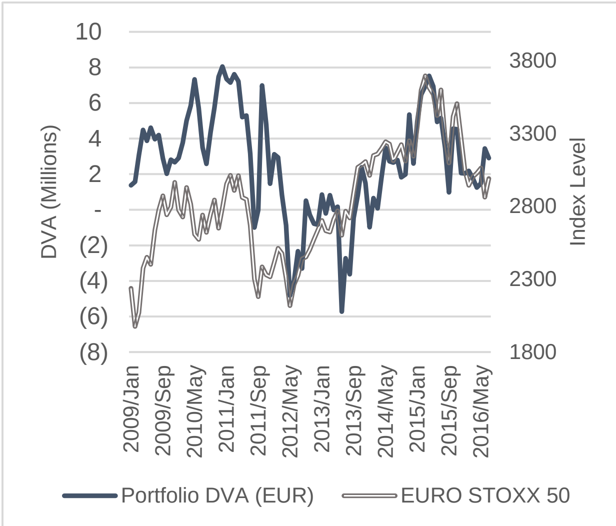


Figure VI: Portfolio DVA compared to EURO STOXX 50 index level from 2009 to 2016

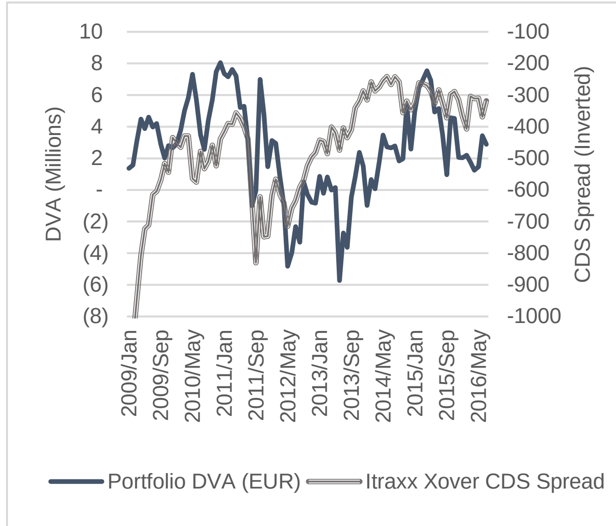


Figure VII: Portfolio DVA compared to Markit Itraxx Crossover CDS spread from 2009 to 2016

The DVA of the portfolio not only changes with the exposure and credit risk, but also new issues have effect. Figure VIII and Figure IX illustrates the change in the DVA from period t to t+1 excluding DVA from new issuances and DVA changes due to maturing DVA. The DVA change is compared to the monthly percentage return in the first future contract of EURO STOXX 50 in Figure VIII and Figure IX compares the DVA change with the monthly percentage returns from investing in Standardized CDS contracts on the most recent series at the time of Markit Itraxx Europe Crossover. Correlated returns are necessary for the hedging strategies to be successful. Again, the returns are at times similar for both assets, while in some periods with opposite signs.

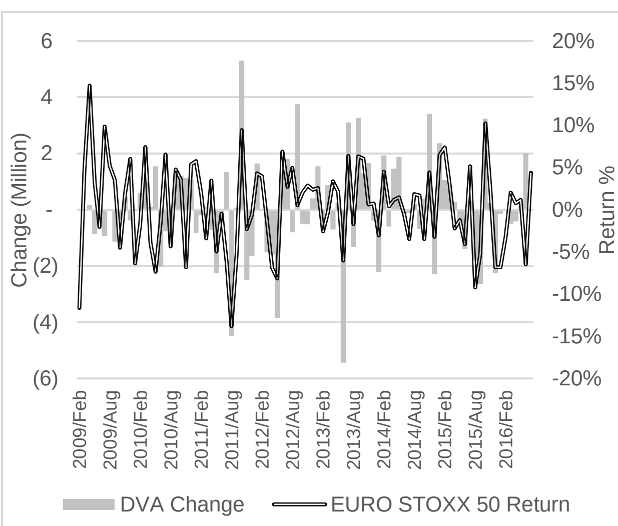


Figure VIII: Changes in DVA of the sample portfolio compared to the return of EURO STOXX 50 from 2009 to 2016

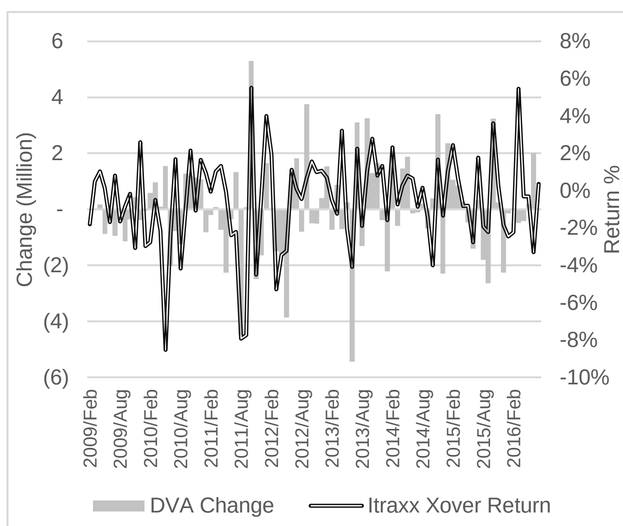


Figure IX: Changes in DVA of the sample portfolio compared to the return of Itraxx Crossover from 2009 to 2016

Results from the Hedging Strategies

In order to measure the significance of the reductions in standard deviations a t-test is used. The t-test statistic is calculated as in Daigler (1998),

$$t = \frac{(\sigma_h^2 - \sigma_u^2)\sqrt{n-2}/2}{\sigma_h \sigma_u \sqrt{1 - \rho_{hu}{}^2}}$$

Where h and u refers to the series of returns of the hedged and non-hedged DVA and ρ_{ab} the correlation between the two.

In addition to the t-test the hedging effectiveness is measured as,

$$Hedging\ Effectiveness = 1 - \left(\frac{\sigma_u^2}{\sigma_h^2}\right)$$

In order to measure the cost in terms of terms of reduced return Sharpe ratios are calculated (Sharpe, 1966). The risk free rate used is the average EUR OIS 1 year rate over the sample period and out of sample period respectively and the arithmetic average monthly return is multiplied with 12 in order to have the annual return. The monthly standard deviation of the returns is multiplied with the square root of 12 to approximate the annualized standard deviation.

The results of the hedging strategies are presented in Table III. Based on the in sample results, the CDS hedge is increasing the total variance of the portfolio in contrary to its purpose. In terms of volatility reduction the best strategy over the sample period is the hedge with EURO STOXX 50 put options. Compared to the annualized volatility of the portfolio DVA the reduction by applying the strategy is 8.33%. However, the Sharpe ratio of the same strategy is the worst of all strategies at -1.21, even worse than the ratio of the unhedged portfolio at -0.50. This implies a very high cost of the hedge strategy. Both option strategies produce reductions significant at a 5%-level. Out of the other strategies only the basket of futures has a significant volatility reduction at 10%-level. The strategy utilizing a basket of futures is also the strategy that produces the best Sharpe ratio for the sample period at -0.39.

In the out of sample period the basket of futures strategy is still producing the best Sharpe ratio of 0.10 followed by the single option hedge at -0.14. The hedging effectiveness increases outside the sample period for all strategies, except for the single option strategy that had the highest effectiveness in the sample period. The highest effectiveness is achieved with the basket of futures strategy at 33.24%. However, none of the reductions in the out of sample period are significant, then again it should be noted that the number of observations in the period is only 12.

For the option hedging strategy a sensitivity analysis is conducted where the term and moneyness of the options used in the strategy are varied. The resulting hedge effectiveness are presented in Table IV in the Appendix. It is clear how the effectiveness decreases with the moneyness of the option and increase with the term. Only in the sample data and the single option strategy does this not hold completely.

Table III: Results from Hedging Strategies

This table presents the results from the five different variations of the hedging strategies. The standard deviation and average return are annualized. The p-value is calculated from a one-sided t-test to show if the reduction of hedge strategies variances compared to the portfolio DVA is significant. The in sample period stretches from 31st January 2009 to 31st July 2015. The out of sample period covers the period 31st August 2015 to 31st July 2016.

	Standard Deviation		**p-value**		**Hedging Effectiveness**		**Average Annual Return**		**Sharpe Ratio**	
	In Sample	Out of Sample	In Sample	Out of Sample	In Sample	Out of Sample	In Sample	Out of Sample	In Sample	Out of Sample
Hedge Strategy										
Portfolio DVA	54.55%	46.56%					-26.70%	-36.76%	-0.50	-0.78
CDS Hedge	54.92%	44.09%	0.549	0.214	-1.36%	10.34%	-24.85%	-25.68%	-0.46	-0.58
Equity Future Hedge Single	52.76%	42.85%	0.137	0.372	6.46%	16.51%	-22.24%	-9.16%	-0.43	-0.21
Equity Future Hedge Basket	49.44%	38.05%	0.073	0.219	17.85%	33.24%	-18.67%	3.43%	-0.39	0.10
Equity Option Hedge Single	46.22%	45.55%	0.022	0.466	28.21%	4.32%	-55.54%	-6.79%	-1.21	-0.14
Equity Option Hedge Basket	49.98%	42.54%	0.026	0.194	16.07%	16.54%	-45.34%	-25.86%	-0.92	-0.60

Discussion and Conclusions

The DVA at the structured notes desk can be defined as the difference between the no-default value of all embedded derivatives of the issued products and the value of the same derivatives after the issuer default risk has been taken into account. The determinants of volatility in the portfolio DVA are the NPV of each derivative, which in turn are exposed to several risk factors, as well as the credit risk of the issuer captured in its borrowing rate. Moreover, the DVA of a single transaction goes to 0 when time passes, which raises the question whether DVA would actually need to be hedged at all as its final value is already determined. For banks in general P/L fluctuations are unwanted, therefore there is a need for considering different hedging strategies.

From the work of other authors it is concluded that the issuer of a derivative cannot replicate its own DVA with a hedging portfolio. This establishes the first constraint when considering hedging strategies. The possibilities for systematic hedge strategies are additionally limited as the strategies are expected to deal with liquid assets and also be manageable. The perfect hedge can therefore quickly be ruled out and the expectations on the remaining options are reduced.

Out of the hedging strategies applied the best performing strategy in terms of hedge effectiveness during the sample period utilized out-of-money 3 month put options on EURO STOXX 50. This method does however come at a high cost as the Sharpe ratio for the period was also the lowest out of all strategies, out of sample it was also the worst performing strategy. The put options provide protections towards market declines, when the market is moving in the opposite direction only the premium of the option is lost. While down-turn protection seems to reduce the DVA fluctuations the cost of the premiums greatly reduce the return. When considering options as hedging instruments the sensitivity analysis shows that the effectiveness seems to decrease with the moneyness, which is a welcome pattern as the premiums are lower for out-of-the-money options. However, the effectiveness increases with the term of the option, which implies increased cost for increase effectiveness.

The second best performing strategy in the sample period used futures contracts on EURO STOXX 50, Kospi 200 and S&P 500 and only the sub-portfolios with exposure linked to the respective regions were considered when calculating hedge ratios. It produces the highest Sharpe ratio both in sample and out of sample and it is the best performing strategy out of sample. Compared to the strategy where only the futures contracts on EURO STOXX 50 is utilized, the strategy has a better fit towards the sub portfolios. This diversification does also seem to reduce the times when the hedge and the portfolio moves in the same direction. It should be noted that the significance of the out of sample results are low due to the few observations, this means that it is difficult to infer any conclusions from the out of sample data further than comparison and indicative results. Furthermore, this study is done on the specific structured notes portfolio of the sample, so generalizations are limited.

The worst performing strategy involved standardized CDS contracts on Markit Itraxx Europe Crossover. While increasing the volatility in the sample period, the out of sample performance was slightly better. The intuition behind using the CDS contracts is to hedge the changes in the credit spread of the issuer with a proxy. The conclusion to draw from the disappointing results is that either the correlation between the issuer spread and the CDS index spread is not sufficient for the hedge to be effective, or that the contributions from the underlying risk factors in the embedded derivatives are greater than the effects from changes in the credit spread. An alternative strategy for proxy hedging the credit spread of the issuer would be to trade CDS contracts on its peers. However, in the Nordics at least, this is potentially very costly due to low liquidity. Additionally, the hedging strategy using CDS contracts could potentially be formulated in a different way. While the DVA always increases with NPV, this is not true for the credit spread. When the credit spread increases, the discount factors decreases. If the NPV of a contract is positive, this means that the difference between the no-default value and the DVA adjusted value increases. However, if it is negative as it can be when the derivative is embedded in a structured note, the change is actually opposite. This means that depending on whether the total DVA is positive or negative, the changes in the issuer credit spread will have different effects.

In the best of worlds, the variance would be minimized when every single risk factor is hedged. However, the practical constraints previously discussed makes it difficult to formulate effective strategies. Lack of market liquidity can be costly and this means that more hedging instruments does not necessarily make the hedge better. Additional improvements can most likely be done to the data quality, more complex strategies can be considered when higher granularity and sensitives are available. This too is costly for the practitioner. Still current data should be available at banks that have already implemented an xVA framework, but possibly not historical data.

Overall, the results could be made stronger. This invites for further research in how the risk factors in the DVA can be hedged with different instruments and strategies. Additionally, the overall effects on the issuer's balance sheet is to be considered. For example, if general down-turns in the economy have effects on the issuers credit spread one would see opposing effects on the banks overall balance sheet. This is usually referred to as right-way risk.

To conclude, there exists no perfect hedge for the DVA in the structure notes book of an issuer. In this thesis the DVA of the structured products portfolio has been defined and different hedging strategies have been assessed with varying results. The strategy that produces the best results in hedging the sample portfolio is a basket of Asian, European and American index futures applied to the sub-portfolios with respect to geographical exposure. The implication of the study for the structured notes desk is that the fluctuations in DVA can be reduced. However, the effectiveness in the hedging strategies is still low and operational costs for setting up a hedge are not considered. It is therefore not an obvious choice for the desk to spend resources on systematic hedging. The findings in this thesis should however be guiding even if the hedging is not systematic. For example, the structured notes desk could consider whether there is a need to implement a strategy at all times and it might prove useful to only hedge in times of high market volatility or ahead of economic events with high attention.

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Appendix

Table IV: Sensitivity Analysis of Option Strategies

This table illustrates the sensitivity analysis of option strategies. The term of the options used and the moneyness (strike) of the options are varied. For the two option hedging strategies the hedging effectiveness measures for in sample and out of sample data is presented in the heat maps. Green is the highest for each individual map and red is the lowest. The strike level of the option is the percentage of the vertical axis times the spot level at the inception of the contract, that is higher strike level implies that the put is more out of the money.

Equity Option Hedge Single

In Sample

Strike level \ Term in Months	1	2	3	6	12
110%	27.12%	27.23%	27.38%	27.34%	26.45%
105%	27.18%	28.30%	28.21%	27.63%	26.22%
100%	25.97%	28.94%	28.98%	27.80%	25.87%
95%	-24.22%	28.22%	29.04%	27.54%	25.27%
90%	-475.32%	18.92%	25.48%	25.87%	24.09%

Out of Sample

Strike level \ Term in Months	1	2	3	6	12
110%	7.48%	6.04%	6.26%	7.46%	8.63%
105%	2.28%	2.57%	4.32%	6.91%	8.53%
100%	-24.40%	-4.94%	0.76%	5.91%	8.26%
95%	-65.70%	-19.56%	-4.85%	4.45%	7.82%
90%	-19.14%	-33.16%	-11.54%	2.64%	7.23%

Equity Option Hedge Basket

In Sample

Strike level \ Term in Months	1	2	3	6	12
110%	16.09%	16.67%	16.73%	16.89%	16.96%
105%	14.34%	15.92%	16.07%	16.26%	16.32%
100%	11.01%	13.74%	14.38%	14.87%	15.05%
95%	-48.61%	8.47%	10.63%	12.10%	12.65%
90%	-187.82%	1.17%	5.03%	8.15%	9.43%

Out of Sample

Strike level \ Term in Months	1	2	3	6	12
110%	14.85%	15.56%	16.35%	17.77%	18.98%
105%	14.33%	15.67%	16.54%	17.94%	19.01%
100%	2.39%	12.95%	15.01%	17.12%	18.37%
95%	-9.56%	4.99%	10.58%	14.84%	16.82%
90%	-48.87%	-4.96%	3.83%	11.49%	14.92%