STOCKHOLM SCHOOL OF ECONOMICS
Department of Finance

Valuation of Structured Investment Products

An Empirical Study of Worst-of Barrier Reverse Convertibles in Switzerland

Master's Thesis in Finance

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Abstract

The thesis examines the valuation of Worst-of Barrier Reverse Convertibles on the Swiss market. This structured product which embeds an exotic option is valued by using an option pricing model of a professional product issuer. We calculate the theoretical price of 434 products and estimate the market values under a given pricing scheme. By employing a regression-based approach, we analyze factors potentially being liable for deviations of actual market prices from theoretical prices. We further use the estimated market values as a benchmark and survey under which circumstances pricing differences between actual market prices and estimated benchmark prices decrease or increase. The analysis reveals that significant factors for explaining deviations between market prices and theoretical prices are difficult to find. However, it is shown that differences between actual market prices and benchmark prices decrease both with decreasing time to maturity and when one or more of the underlying assets have touched the barrier level.

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Discussants	Insert comment.

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Acronyms

AuM	Assets under Management
DIP	Down-and-in put option
EFG FP	EFG Financial Products
MCS	Monte Carlo Simulation
RC	Reverse Convertible
SMI	Swiss Market Index
SSPA	Swiss Structured Products Association
SWX	Swiss Exchange
WBRC	Worst-of Barrier Reverse Convertible
WODIP	Worst-of down-and-in put option

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1 Introduction

Structured products have gained in importance during the recent years. Switzerland is thereby the largest market worldwide, with currently CHF 341bn assets invested in such products (SSPA, 2007). The market is developing extremely fast and several new competitors are entering each year. With the increasing number of product issuers the competition becomes more intense and the focus shifts towards service, transparency and a competitive pricing. While prices are difficult to compare for retail investors, institutional investors focus in an increasing manner on the price of the products. Thus, offering competitive prices is becoming key.

In this master thesis we analyze the Swiss market for structured products. We focus on the valuation of Worst-of Barrier Reverse Convertibles (WBRCs) and examine differences between various product issuers. WBRCs offer investors attractive coupons during times when markets are moving sideways. Because of this attribute, they are among the most successful products on the market. WBRCs comprise both a zero coupon bond and an exotic option component. The latter makes the valuation of such products a complex task and can give rise to large valuation gaps between different parties.

Previous studies have analyzed structured products on the Swiss and the German market and have found large differences among the issuers. These differences may arise from unique valuation models, varying views on the market or differing pricing schemes. For an issuer, knowing and understanding these differences is important as it is a crucial step towards offering competitive prices. Surprisingly, comparisons of products with exotic option components have rarely been conducted on a large scale neither by academics nor by the issuing companies (Stoimenov & Wilkens, 2005).

The purpose of this thesis is to investigate pricing differences between the leading financial institutions on the Swiss market. During a three months project at EFG Financial Products (EFG FP) in Zurich, Switzerland, we have analyzed the valuation of WBRCs on the secondary market. Using the pricing model of EFG FP as a black-box model, we calculated the theoretical price of 434 products of different maturities with underlying assets from the Swiss Market Index (SMI). By employing a regression-based approach, we looked at factors which are potentially liable for deviations of market prices from theoretical prices. We further estimated the prices which EFG FP would ask for the same products and use these prices as a benchmark. We analyzed under which circumstances pricing differences between market prices and benchmark prices decrease or increase.

The results of our study are presented in this research paper. Since our work was heavily dependent on proprietary data from an existing product issuer, we only publish information that does not reveal confidential data on the business of EFG FP. In particular, we refrain from explaining the pricing model in detail. Nevertheless, we are convinced that the results published in the paper are interesting from an academic point of view as it gives insight into the structured products market and the valuation of WBRCs and adds in many ways to the existing literature.

The thesis addresses anyone who is interested in derivatives and investments. Despite dealing with exotic options, it was never attempted to make this research paper a quantitative one. While a basic understanding of derivatives and the Black-Scholes model is certainly advantageous, any educated reader with a finance background should be able to follow the analysis and understand the results. No deep knowledge of mathematics is required. In case we believe that readers may be interested in knowing more about the mathematics behind the theory, we refer to the respective literature.

1.1 Clarification of terms

In order to follow our research, it is essential to understand the different price metrics that we used for testing our hypotheses. Hence, we introduce and define the terms *market price*, *theoretical price* and *benchmark price* at this point.

Market price refers to the ask price of a competitor product as quoted on Reuters. It is the price that the respective issuer of a product is demanding for a given product. Market prices always correspond to the prices of products offered by competitors of EFG FP.

Theoretical price refers to a hypothetical price that we calculated using the option pricing model of EFG FP. It is the price for which a professional market participant would be able to construct the WBRC and includes hedging costs. Most importantly however, the theoretical price excludes any type of premiums that product issuers may charge.

Benchmark price refers to a hypothetical price that we calculated using the option pricing model of EFG FP. It is the ask price that EFG FP would be demanding for a given product if it was the institution which issued the product. As such, it includes the full costs related to hedging activities and all adjustments for a typical pricing scheme of EFG FP.

1.2 Outline

The remainder of this thesis is organized as follows. Section 2 presents an overview of structured products and explains the characteristics of WBRCs. Section 3 gives insight into the theoretical framework concerning the valuation of barrier options. Section 4 builds up on the existing research and formulates our hypotheses. Section 5 provides a description of the data and methodology applied in our research. Section 6 discusses the empirical findings and section 7 concludes our study.

2 Background

2.1 Definition of structured products

There is no consistent and widely accepted definition of the term structured product available in the academic literature. Although conveying the same idea, every author defines the term slightly differently. We will present the one definition that we find is the most complete and accurate of all.

A structured product combines the payout structures of at least two financial assets into one financial product, where at least one of these components has to be a derivative financial instrument (Wohlwend, 2001, p.5).

2.2 Product types

The distinctive feature of structured products is that almost any payout structure can be reproduced by combining the payouts of different financial assets. In this way, structured products can be tailor-made according to the ideas of the investor. This makes it difficult to keep track of the numerous products and to categorize them in a logical manner. For this reason, there cannot be found any universal standard for classifying the different types of structured products. Probably the most widely used is the categorization model of the Swiss Structured Products Association (SSPA).

SSPA is an association that maintains and represents the shared interests of the major issuing companies in the Swiss structured products market. One of its goals is to bring more clarity and transparency into the Swiss market so that retail investors are able to make more informed decisions. The categorization of structured products is one of the measures to achieve the proclaimed purpose. It applies to products listed on the Swiss Exchange (SWX) and displays all product types that are on the market as of March 2008. Altogether, SSPA distinguishes between four main groups and 20 different product types. The categorization is illustrated in Figure 1[1].

Categorization model

Leverage products	Participation products	Yield enhancement products	Capital protection products
Warrants	Tracker certificates	Discount certificates	Uncapped capital protection
Spread warrant	Bonus certificates	Barrier discount certificates	Capped capital protection
Knock-out warrants	Outperformance certificates	Reverse convertibles	Capital protection with coupon
Mini-futures	Airbag certificates	Barrier reverse convertibles	
	Twin-win certificates	Barrier range reverse convertibles	
		Capped outperformance certificates	
		Express certificates	
		Capped bonus certificate	

Figure 1: SSPA categorization of product types

[1] For a detailed description of each product type we refer to the website of SSPA, www.svsp-verband.ch.

2.3 Benefits of structured products

From the investor's perspective structured products pose several advantages. First, the investor is able to gain access to financial instruments, such as options or futures, which due to their large contract size are typically reserved for bigger market players such as financial institutions or high net worth individuals. Further, structured products offer investment possibilities into almost any asset class such as commodities, fixed income, alternative investments, equities and real estate. Additionally, the investor is able to pursue complex trading strategies with exotic payouts simply by buying one packaged product (SSPA, 2007). Otherwise he would have to buy each single component separately, which is more time consuming, requires profound knowledge of derivative instruments and likely to be more costly for the investor. Another important feature is that structured products enable the investor to profit from a sideways moving or bearish market, which is often done by writing put or call options. Engaging in a short option position is not possible for many investors because of margin requirements that have to be met. Finally, the issuing bank provides a liquid secondary market which facilitates the selling of otherwise illiquid instruments.

2.4 The Swiss structured products market

While structured products became popular in the US already in the 1980s, the first structured product in Switzerland was issued in 1991. In the late 1990s structured products gained popularity due to the fact that interest rates in Switzerland were at a historically low level (Burth et al., 2001). Especially so called yield enhancement products found numerous buyers during that period. Today, Switzerland is the largest market for structured products in the world with assets under management (AuM) of over CHF 341bn (SSPA, 2007). There are approximately 30 issuing companies active in the market that account for over 17000 listed products (Scoach, 2008).

In the recent past the demand for structured products has been increasing rapidly. This development is best captured by the amount of AuM which has seen growth rates of over 30% in the last two years. It is estimated that over the course of the next two to three years the market will further grow by over 20% per year (SSPA, 2007). Compared to other asset classes, the average investor holds 6.45% of his portfolio invested in structured products. SSPA estimates that in the next five years this amount will rise to over 10%. Nonetheless it is still the case that institutional investors are the largest buyers of structured products accounting for more than 50% of the structured products market.

2.5 Reverse Convertibles

In order to understand WBRCs, we will first explain the standard Reverse Convertible (RC). RCs or equity-linked bonds are bond-like securities that offer a coupon that is considerably higher than the risk-free interest rate (Wilkens & Röder, 2003). As can be seen from figure 1, RCs belong to the group of yield enhancement products. Hence, RCs are ideal for an investor who expects that the market moves sideways or slightly higher. If his market expectation is accurate he earns a return above the underlying asset's return by receiving relatively high coupons. Further, it is beneficial to buy the product if volatility has peaked and is expected to decline in the near future, as the investor is essentially shorting volatility. Regarding the payout of RCs there are two possible scenarios. If the price of the underlying trades above the strike price at maturity the payout of RCs is equal to a coupon bond, i.e. the investor receives the coupon and the principal payment. In case the underlying closes below the strike price at expiry the investor is paid out the coupon and is delivered the underlying. Depending on the issuer, the coupon is paid out annually or semi-annually.

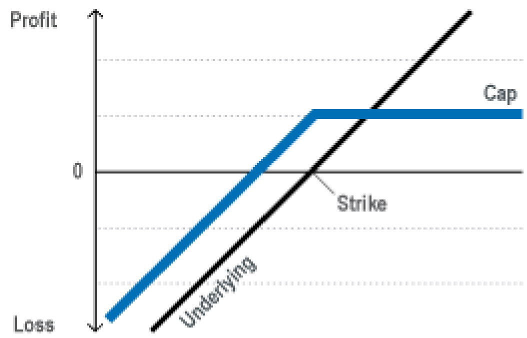

Figure 2: Profit diagram Reverse Convertible (SSPA, 2007)

A RC is constructed by combining a long bond with a short put option. The resulting profit pattern is illustrated in Figure 2. When looking at the profit diagram, RCs resemble the same profit pattern as a short put position or a covered call. The only difference is that the profit line is higher by the amount of the coupon payments of the bond. A critical reader might wonder why such a structured product exists if one could simply short a put option. The answer is that for most retail investors writing options is simply not possible as it is too risky and the process of getting the permission from the depository bank is inconvenient. By issuing RCs, financial institutions provide their clients with the possibility to pursue such an investment strategy by simply buying the product. The bond component thereby serves as collateral for the short put position held by the investor.

2.6 Worst-of Barrier Reverse Convertibles

WBRCs differ from simple RCs in two respects. First, WBRCs are constructed on a basket of underlying stocks, i.e. they have multiple underlying assets. In the Swiss market the majority of WBRCs are structured on three underlying assets, however there are also products on two, five or even more underlying assets. The second difference from standard RCs is that WBRCs contain a barrier level, which serves as a conditional capital protection against price decreases in the underlying. As long as none of the underlying stocks touches the barrier level during the product life, the investor receives the coupon and the principal payment. If one of the underlying stocks touches the barrier level at any point during the product life, the WBRC loses its downward protection and converts to a standard RC on the worst performing underlying stock.

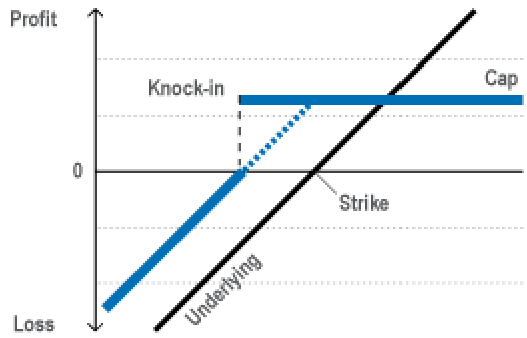

Figure 3: Profit diagram Barrier Reverse Convertible (SSPA, 2007)

The described payout function of WBRCs is illustrated in Figure 3. The profit diagram shows that until the knock-in is reached the product has the same payout as a bond, which is highlighted by the bold line. Once the barrier is touched, the WBRC transforms to a standard Worst-of RC which is indicated by the dotted line. This payout function is achieved by combining a short position in a worst of down-and-in put option (WODIP) on multiple underlying stocks and a long position in a discount bond. As the name already suggests, the option is not plain-vanilla but of exotic nature. It belongs to the category of barrier options, which will be explained in detail in the next section. Similar to the standard RC, the market expectation for WBRCs is a sideways trend or slight increase in the underlying assets during the life of the product. Generally the maturity for WBRCs is fixed at 1 year, which is mainly due to tax reasons.

3 Theoretical framework

In this section we present the theoretical framework necessary to understand WBRCs. We focus on elaborating on the characteristics and the valuation of the exotic option component. We further show how the price of the product is calculated.

3.1 Option component

3.1.1 Worst-of barrier option

The option component of the WBRC is represented by an exotic option, a barrier put option. Exotic options differ from plain-vanilla put or call options by containing additional features. Barrier options are options where the payoff depends on whether the underlying asset's price touches a predetermined level during a certain time period (Hull, 2006). Barrier options can be classified as either knock-out or knock-in options. While the former cease to exist when the underlying asset touches the barrier, the latter only come into existence once the barrier is touched. Plain vanilla barrier options can be classified in the following way:

Option type	Definition
Up-and-in barrier option	The option becomes active when a specified barrier level is reached before expiry. This barrier level lies above the initial value of the underlying asset.
Down-and-in barrier option	The option becomes active when a specified barrier level is reached before expiry. This barrier level lies below the initial value of the underlying asset.
Up-and-out barrier option	The option is active as long as a specified barrier level is not reached before expiry. This barrier level lies above the initial value of the underlying asset.
Down-and-out barrier option	The option is active as long as a specified barrier level is not reached before expiry. This barrier level lies below the initial value of the underlying asset.

Table 1: The four basic forms of barrier options (Wilmott, 2006)

In addition to the basic forms of barrier options a number of more exotic barrier options exist on the market. Examples of such options are options with partial barriers, double barriers, time-dependent barriers and compound barriers (Brockhaus et al., 1999). All barrier options have in common that they are path-dependent. Thus, the final payoff of the option is not only determined by the final value of the underlying but it also depends on the path of the underlying asset during the life of the option.

WBRCs are structured with a WODIP, i.e. an option which comes into existence only when the barrier is touched. In addition to the barrier component, the option incorporates a worst-of feature. This feature means that the option has a number of stocks as underlying assets[2]. All of the underlying stocks can trigger the barrier level. Once the barrier level is touched by any of the underlying stocks the put option becomes active. At the end of the life of the product the put denotes on the worst

[2] Note that the underlying assets are not restricted to stocks.

performing stock. This is independent of whether the worst performing stock has actually touched the barrier level or whether it was another stock touching the barrier. In case all stocks close above the respective strike levels the put option expires worthless. In case one or more stocks close below the strike levels and the barrier was touched the put will be executed as it closes in-the-money. The buyer of the WBRC who is short the put option will then receive a predefined number of the worst performing stock.

The payoff function at maturity *f(S(T))* of a down-and-in put option (DIP) on a single underlying can be described as follows:

$$f(S(T)) = \begin{cases} 0 & \text{if } S(t) > B \text{ for all } t \in [0,T] \text{ or } S(T) \geq K, \\ K - S(T) & \text{else.} \end{cases} \tag{1}$$

where S denotes the price of the underlying asset, B the barrier level and K the strike price.

3.1.2 Factors affecting the option price

The determinants for the value of barrier options are in principle the same as for plain-vanilla options. As described by Black and Scholes (1973) options are dependent on the current price of the underlying, strike price, time to expiration, volatility of the stock, risk-free interest rate and dividends expected during the life of the option. While these factors are all highly relevant for barrier options, they do not always influence the barrier option in the same way as they influence plain-vanilla options. This is especially true when the underlying stocks trade around the barrier level. Consider a down-and-in call option and its relationship to the underlying stock. As long as the barrier is not touched, the option has no intrinsic value. Thus, the value of the option increases when the underlying asset decreases. Once the barrier is touched, the relationship changes. The value will then decrease with a decreasing underlying asset, similar to an ordinary call option. In essence, the down-and-in call is equal to an out-of-the-money plain-vanilla call option once the barrier is touched. Such exotic relationships are also observable for the other pricing factors.

In addition to the six determinants of the Black-Scholes model, the barrier level and monitoring frequency further influence the price of the option. In case of the DIP as used for the WBRC the influence of the barrier level is positive, i.e. the price of the option increases with an increasing barrier and vice-versa. Irrespective of the barrier level, a barrier option is always worth less than the same plain-vanilla option as the holder gives up some of the option rights (Reinmuth, 2005). The monitoring frequency influences the value of the option in the same way as the barrier level. The value of the option raises when the monitoring frequency increases, and vice-versa. For structured products sold on the Swiss market we generally observe continuous monitoring. Thus, if the underlying asset's bid price touches the barrier level at any time, the barrier event is considered to have occurred.

For WBRCs the put option is generally constructed in the following way. The strike prices of the underlying stocks are fixed at the level of the underlying stocks at time of issuance. The barrier levels are quoted in percentage of the initial level of the underlying assets. For example, a product with ABB, Nestlé and Roche as underlying stocks could look as following:

Underlying stock	**Price at issuance**	**Strike price**	**Barrier level**
ABB	CHF 26.00	CHF 26.00 (100%)	CHF 17.94 (69%)
Nestlé	CHF 482.50	CHF 482.50 (100%)	CHF 332.92 (69%)
Roche	CHF 203.50	CHF 203.50 (100%)	CHF 140.42 (69%)

Table 2: Sample WBRC

3.1.3 The Greek letters

In this section we discuss the dynamic nature of the barrier option's value represented by the Greek letters[3]. The Greek letters for barrier options are calculated in almost the same way as for plain-vanilla options. The only difference lies in the option model used to derive the sensitivities (Reinmuth, 2005). The differences in behavior can however be quite large, in particular when the underlying assets are close to the barrier level. We will now illustrate such a behavior with the example of a DIP. The DIP is the one that generally behaves most like a plain-vanilla option (Chriss, 1997). Nevertheless, the differences can be large around the barrier level. As mentioned, this is the option used when constructing a WBRC and understanding the sensitivities of such an option will help understanding the specifics of this structured product. The following explanations are based on Reinmuth (2005).

If the underlying trades above but close to the barrier, the delta of a DIP can easily go below minus one. The reason for this is that the payoff differs significantly depending on whether the barrier is touched or not. Moving further up from the barrier level the delta approaches zero much faster compared to plain-vanilla put options. Due to large changes in delta, the gamma of a DIP is generally highest when the underlying trades around but above the barrier. This is different from a plain-vanilla put option where gamma is highest when the underlying trades around the strike price. Further, the effect is larger when there is only little time to maturity left.

The vega of a DIP is considerably high around the barrier due to higher probabilities that the barrier will be touched. Different from plain-vanilla put options, the vega does not evolve around the strike price. The maximal value of vega is approximately the same for different maturities. The theta of a DIP can be compared to the theta of a plain-vanilla option with longer maturities. With shorter maturities, the theta of a DIP is often much lower. While rho decreases slightly more compared to plain-vanilla options, it is fairly similar and much dependent on the outstanding life of the option.

The above description of Greek letters for the DIP points out an important aspect for the pricing of WBRCs. The most important factor for such a product is not where the strike price is set, as is

[3] For explanation of Greek letters, see appendix D.

generally the case for products with plain-vanilla options. The key determinant for pricing WBRCs is the barrier level. While this holds true for the Greeks, it is also important for the risk and return measures. Products with high barrier levels can offer a higher coupon but are heavily exposed to negative market movements. Products with a low barrier offer the investor a lower coupon but the capital is much more protected.

3.1.4 Worst-of feature

While the above description focused on explaining the basic forms of barrier options, we now want to show the implications of the worst-of feature. Options on more than one underlying assets are of great importance for the structured products market. The most important implication of the worst-of feature is that there are more factors affecting the pricing of a WBRC[4]. In case the barrier is touched by at least one underlying and at least one of the underlying assets closes below the strike price, the investor receives the worst performing underlying stock.

Understanding the meaning of the worst-of feature one can easily see that the correlation of the underlying assets becomes fundamental. Lower correlation leads to a higher probability of a single extreme event. This increases the likeliness that the barrier will be touched during the life of the option and that the option becomes active. As the option offers a right but not an obligation, it is clear that the option becomes more valuable with decreasing correlation and less valuable for underlying assets with high correlation.

In the case of falling markets the implications of the worst-of feature can be very negative. Instead of participating in a portfolio of stocks the investor participates in the worst performing stock once the barrier has been touched. The loss will then by definition be larger than the portfolio loss since stocks do not correlate perfectly (Ammann & Ising, 2007). Thus, the worst-of feature makes the product riskier and is one of the reasons why products can offer high coupons. This makes the correlation essential for pricing WBRCs, comparable with the barrier level. The risk of a product increases with decreasing correlation and decreases with increasing correlation.

In practice, the correlation is generally obtained by using shifted historical correlations as implied correlation for a given pair of underlying assets is not easily observable in the market (Lenglet, interview on 28/02/2008). Each trader will have a different method to generate correlations which can be a cause for pricing differences between different issuers. A possibility would be to take a combination of historical correlations, for example from the last three years.

[4] For more information on the valuation of multi-asset options see Wilmott (2006) and Dai (2008).

3.1.5 Pricing the barrier option

While the above section aimed for conveying knowledge about the characteristics of the barrier option, we will now point out how such options can be valued. As will be shown, in spite of many existing valuation methods the one most widely used is Monte Carlo Simulation.

3.1.5.1 In-out-parity

The in-out parity can be compared with the put-call parity for plain-vanilla options. In both cases, one instrument is replicated by the use of other financial instruments. The in-out parity is an important relationship to price barrier options. All models must satisfy this in-out parity (Derman et al., 1995). It further offers important implications for hedging purposes.

The parity says that the result of combining a down-and-in option with a down-and-out option of the same type with equal strike prices and maturities is a plain-vanilla option of the same type (Chriss, 1997). Formally, the parity can be written as follows:

$$\begin{aligned} Call &= Call_{in} + Call_{out} \\ Put &= Put_{in} + Put_{out} \end{aligned} \tag{2}$$

This follows when looking at a knock-out and a knock-in option with the same strike prices and maturities. One option will be knocked out when the other one is knocked in. Independent of the development of the underlying there will always be one active option at maturity date. Thus, the joint payout function equals precisely the payout function of a plain-vanilla option. Because of the no arbitrage condition, the two barrier options need to be priced in line with the plain-vanilla option (Chriss, 1997). Note however that the argument only holds for European options.

3.1.5.2 Analytical valuation

A formula for a down-and-out call option was first introduced by Merton (1973). Reiner and Rubinstein (1991) provided the framework for valuing all eight types of barrier options with analytical formulas. These formulas are based on the assumptions of the Black-Scholes model but are modified to take into account the existence of the barrier. As Reiner and Rubinstein explain, barrier options are somewhat intermediate of European and American plain-vanilla options. Similar to American options their value depends on how the underlying evolves over the life of the option. Yet, they are easier to value since the boundary is determined in advance. Consequently it is possible to state closed form solutions for such options using the boundary conditions.

The analytical formulas have however several drawbacks. Using analytical formulas for pricing barrier options is only possible assuming a European style option with a fixed barrier and continuous monitoring (Reinmuth, 2005). The dependency on the Black-Scholes assumptions reveals another shortcoming. Barrier option prices are especially sensitive to volatility due to their path-dependency and using the closed-form valuation may not be very accurate (Chriss, 1997). Thus, the analytical valuation approach is typically not used for pricing the WODIP.

3.1.5.3 Numerical valuation

The above description shows that analytical valuation formulas are very much restricted and thus of limited practical use. Numerical valuation methods such as binomial trees, trinomial trees, implied trees and Monte Carlo Simulation promise greater flexibility and more practicability. Several such methods have been developed that allow taking into account the different characteristics of barrier options. They can be used to value options with discrete monitoring, options with underlying assets paying discrete dividends or American style options (Reinmuth, 2005). Of great importance for issuing structured products is the ability of some valuation models to account for specific volatility surfaces and options on multiple underlying assets. While all of the numerical methods are important, the method most widely used for pricing worst-of barrier options is the Monte Carlo Simulation. In the following, we focus on explaining how Monte Carlo Simulation is used when pricing barrier options[5].

3.1.5.4 Pricing by Monte Carlo Simulation

Pricing by Monte Carlo Simulation (MCS) is in theory straightforward. All that needs to be done is to select a model for the stochastic process of the underlying assets, simulate the development of the underlying assets during the life of the option, calculate and discount the option payoff, repeat the procedure many times and calculate the average of the discounted payoffs (Wilmott, 2006). This discounted average will then be the value of the option. When using MCS for barrier options, some particularities need to be taken into account (Reinmuth, 2005). Since barrier options are path-dependent, it is not enough to simulate only the final value of the underlying assets. It is further important that many values around the barrier level are captured and that the development of the underlying assets is examined in line with the monitoring frequency.

There are good reasons why MCS is often used for non-standard option contracts. MCS offers virtually no limitations on the type or complexity of the option to be priced (Pätzold, interview on 17/03/2008). MCS allows adjusting for several stochastic parameters, as for example a non-constant interest rate or a non-constant volatility. It is further of great importance as it can be used with multiple underlying assets. Stock price simulations can easily take into account the correlation factor. The simulation of the developments will be much closer to reality than with any other method used (Reinmuth, 2005). The shortcoming of MCS is that a very large number of simulations are needed in order to achieve accurate option prices. This makes it often a practical challenge to implement MCS.

[5] For a complete overview on the valuation methods see Reinmuth (2005) and Wilmott (2006).

3.1.5.5 Local volatility

The basic Black-Scholes option pricing model assumes that the underlying follows a geometric Brownian motion, which can be written as (Hull, 2006):

$$\frac{dS_t}{S_t} = \mu\, dt + \sigma\, dW_t \tag{3}$$

where S denotes the price of the stock, μ the expected rate of return and σ the volatility of the stock price.

As can be seen the process of the stock price is modeled with a volatility factor that is held constant. However, the assumption that volatility is constant does not hold in the market place. This becomes apparent when theoretical Black-Scholes option prices with one constant volatility are compared to market prices of listed options. Typically, one finds that the prices do not match (Blacher, date n/a). This is due to the fact that market participants use an implicit volatility that varies with the maturity and the strike price of the option. The former relationship is known as the term structure of volatility, which illustrates different implied volatilities as maturity goes forward. The latter relationship is commonly referred to as the volatility smile or in the case of equities the volatility skew (Hull, 2006). The volatility skew for equities is negative, which means that volatility decreases with an increasing strike. Holding everything else constant, a deep-out-of-the-money put always trades at a higher implied volatility than a deep-out-of-the-money call. Interestingly, the volatility skew has only come to existence after the crash in October 1987. Rubinstein refers to this phenomenon as crashophobia, the fear of a market crash. It is this fear that prompted traders to price options accordingly (Hull, 2006).

Plotting the implied volatility as a function of both the option strike and option maturity produces the implied volatility surface. Figure 4 depicts the volatility surface, where the skew is clearly visible.

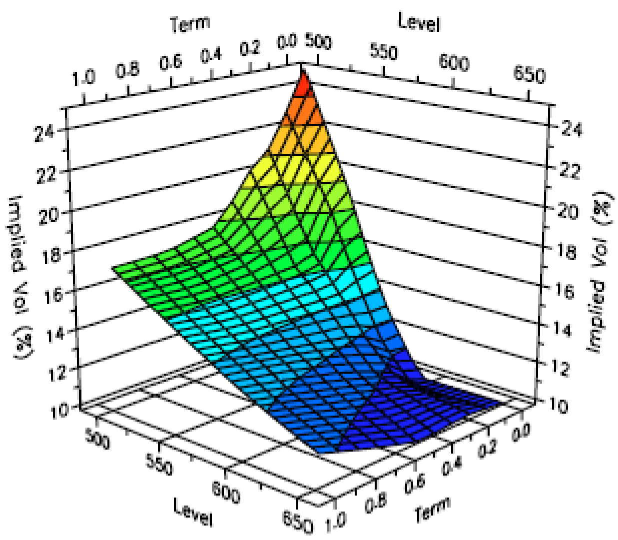

Figure 4: Implied volatility surface (Derman et al., 1996)

According to Derman et al. (1996), option traders regard the implied volatility, i.e. the Black-Scholes volatility implied from market prices, as the estimated average future volatility of the underlying asset during the life of the option.

For calculating the value of European style plain-vanilla options, the implied volatility is generally being used. However, for pricing barrier options one encounters several issues when using the same implied volatilities. Suddenly the question arises which one is the appropriate implied volatility for computing the option price (Derman et al., 1996). As such, one could think of either the implied volatility at the strike price or at the barrier level. Both of these volatilities seem to be incorrect. In order to solve this difficulty, practitioners typically use a local volatility framework instead of the implied volatility. Different from the implied volatility, local volatility is the volatility of the underlying at a future time and future underlying level. Thus, instead of modeling the stock price with constant volatility, in a local volatility framework it is modeled with a volatility that is a function of time and the future level of the underlying asset. This is expressed by the following process as given in Derman and Kani (1994):

$$\frac{dS_t}{S_t} = \mu\, dt + \sigma(S,t)\, dW_t \tag{4}$$

where $\sigma(S,t)$ denotes the local volatility function dependent on both the stock price and time.

Derman and Kani (1994) deduce the local volatility function $\sigma(S,t)$ numerically from the implied volatilities of listed plain vanilla options. The function is determined by fitting the calculated prices by the model to the prices given by the market. In order for this to work, the option prices of all strikes and maturities are required. Since the market only quotes options with a few strike levels and maturities, there is the need to interpolate the ones that are missing. On the other hand, Dupire (1993) comes up with an explicit formula that derives the local volatility function $\sigma(S,t)$, which means that the model does not have to be calibrated to market prices. This is the approach that is generally used by issuing institutions for pricing path-dependent options. Again, this equation can only be derived if all option prices at all strike and maturity levels are available.

Perhaps a more intuitive way to understand the concept of local volatility is brought forward by Derman et al. (1996) who compare the relationship between the implied volatility and the local volatility to the one between the yield to maturity and the forward rate in the fixed income market. While the yield to maturity of a bond is the constant discount rate over its maturity, the forward rate is the discount rate at a future point in time deduced from the yield curve. In the same sense, the authors argue that the implied volatility of an option is an estimate of the average future volatility during the options lifetime, while local volatility is in fact the volatility at a future point and underlying level.

3.2 Bond component and product quoting type

WBRCs are quoted in percentage instead of absolute values. This is mainly due to the fact that prices are easier to compare if quoted in percentage as the denomination (most often CHF 1,000 or CHF 5,000) of a product can vary between products and issuers. At time of issuance, the price of a WBRC is always set at 100%. The procedure of arriving at the initial price will be explained by the following illustration of a one year WBRC.

First, the price of a standard zero coupon bond with a maturity of one year is computed. In the next step, the discounted coupons of the product are added. Lastly the value of the WODIP is subtracted to arrive at 100%. The calculation of the WBRC is provided in the formula below:

$$Price_{WBRC} = ZeroCouponBond_{PV} + Coupon_{PV} - WODIP \qquad (5)$$

Although all issuers quote WBRCs in percentage, they do not treat accrued interest in a consistent manner. One has to distinguish between issuers which quote dirty prices and issuers quoting clean prices. The dirty price is the price including accrued interest payments and is calculated as in equation 5. The clean price is the price excluding accrued interests. In order to make the prices comparable, we employ the following formula:

$$Clean\ price = Dirty\ price - \left(100 \cdot \frac{Coupon\ rate}{Coupon\ frequency} \cdot \frac{Number\ of\ days\ passed}{Number\ of\ days\ in\ period}\right) \qquad (6)$$

4 Previous research and hypotheses

Having explained the characteristics of barrier options and the construction of WBRCs, we will now move on with an overview of the previous literature on the topic of structured products. The following hypotheses will then build up on the existing literature and the valuation particularities described above.

4.1 Previous research and contribution

Only few recent studies deal with the valuation and pricing of structured products. Among the first ones are Chen and Kensinger (1990) who investigate derivative products with a capital guarantee issued by commercial banks on the US market. Based on a comparison of the implicit volatility of index options and the options within the index certificates, the authors find significant deviations in the pricing of most of the products. Similar results are found in a study on US index notes. The study by Chen and Sears (1990) reveals an initial overvaluation of up to 5% which declines throughout the life of the product.

Structured products traded on the Swiss market are first investigated by Schenk and Wasserfallen (1996). Their research focuses on the valuation of thirteen capital protected products on the SMI throughout a year. Comparing the weekly closing prices of the products with their theoretical value, the authors find similar results to Chen and Sears. These products tend to be overvalued at the issue date whereas the overvaluation declines with time. With regards to fairness in pricing, the authors infer that the analyzed products are priced reasonably.

While all above-mentioned studies are based on a relatively small product sample, Burth, Kraus and Wohlwend conduct a more extensive study on the Swiss market in 2001. The authors examine the pricing of 275 Discount Certificates at time of issuance, with the largest Swiss companies as underlying assets. The results reveal a deviation from the theoretical values of 1.4% on average. They further show that the pricing can differentiate noticeably depending on the issuing financial institution.

A similar study is performed by Wohlwend in the same year. The author looks at 192 structured investment products (of which 16 include embedded exotic options) both on the primary and secondary market. He further examines several parameters likely to influence the pricing. The author finds indications of large differences among different product classes and a positive influence of a high rating on the valuation of the products in the secondary market. For the first time, Wohlwend investigates the influence of a co-lead manager on the pricing and finds that products issued in collaboration with a co-lead manager are priced more competitively.

More recent studies were conducted on the German market. Erner, Röder and Wilkens (2003) look at 170 Reverse Convertibles and 740 Discount Certificates. Based on a replication strategy using call options traded on the Eurex, they find comparable results to the ones on the Swiss market. They show that there are significant differences between the costs of the strategy and the structured products. In a follow-up study by Stoimenov and Wilkens (2005), some driving factors behind the issuer's pricing policies are being analyzed. As such, they identify underlying (stock vs. index) and type of implicit derivative (plain-vanilla vs. exotic) as driving factors on the primary market. Products with embedded exotic options are subject to higher premiums compared to classic products. For the secondary market they find that the product life cycle is a driving factor of the premium, i.e. surcharges decrease as products approach maturity.

Muck (2005) investigates the pricing of exchange traded Turbo Certificates and OTC retail derivatives on the German market. He finds that OTC products are more expensive due to imperfect competition and limits to arbitrage. Further, the author tests the product life cycle theory by Stoimenov and Wilkens. Somewhat contrary to Stoimenov and Wilkens, Muck finds only weak evidence for the existence of a product life cycle of Turbo Certificates.

The research overview presents several aspects of the structured products market that have been analyzed up to now. Nevertheless, there are still many areas in which research needs to be done. This master thesis aims for expanding the existing research in the following aspects: In contrast to the studies by Chen/Kensinger, Chen/Sears and Schenk/Wasserfallen our dataset with 434 analyzed products is much more extensive and focused on the current market environment in Switzerland. As opposed to Burth/Kraus/Wohlwend and Erner/Röder/Wilkens and few master theses from other universities[6], this study includes structured products built with exotic options. Compared to Wohlwend, Stoimenov/Wilkens and Muck, the study at hand focuses on WBRCs, a product on which little research has been done as yet. Finally, this thesis examines the market for WBRCs from a practical point of view and has been conducted for helping EFG FP to understand the competitiveness of its own pricing. While most above-mentioned studies computed the products with a simple replication strategy, our study makes use of a professional valuation model that is being utilized in the largest market for structured products worldwide. Therefore, we believe that our results are likely to be much closer to the real life numbers.

4.2 Hypotheses

Hypothesis 1: Products with underlying assets trading closer to the barrier level show higher absolute pricing differences.

The valuation of barrier options is not as straightforward as valuing plain vanilla options. Expectations on the pricing influencing parameters such as volatility or correlation of the underlying assets need to

[6] See for example Ruch R. (University of St. Gallen)

be taken into consideration. While there are some common practices, it is very much up to the trading desk to measure and implement an appropriate method to deal with these factors. This leads to differences between the issuers. The barrier level can be seen as the key determinant of pricing barrier options. When an underlying asset trades around the barrier product prices react very sensitively. The Greek letters (delta in particular) emphasize this point. We believe in case one or more of the underlying assets trade close to the barrier level, expectations of traders on the influencing parameters will have the highest effect. Thus, absolute pricing differences between market prices and benchmark prices will be at the highest when the underlying assets trade close to but above the barrier level.

Hypothesis 2: Absolute pricing differences decrease with time.

At time of maturity, the market price of a product is easy to calculate. It equals 100% if the barrier was either not touched or all underlying assets close above their initial level. Otherwise the price is equal to the market price of the worst performing underlying stock adjusted for conversion ratio. Thus, there should be no pricing difference at maturity. Stoimenov and Wilkens (2005) have tested for the development of product prices on the German market and found that deviations from theoretical prices are decreasing over time. We expect to see a similar relationship for absolute differences between market prices and benchmark prices. The converging prices are not explained by decreasing margins since benchmark prices are adjusted for margin effects. We believe that differences due to different models and valuation methods are declining towards maturity date because of a decreasing uncertainty. Hence, we expect absolute pricing differences between market prices and benchmark prices to decrease with time.

Hypothesis 3: Products where one or more of the underlying assets have touched the barrier level are priced more consistently.

WBRCs are constructed with a zero coupon bond and a worst-of down-and-in put option. Once the barrier is touched the put option becomes active. Effectively, the WODIP becomes a simple worst-of put option once the barrier is touched. This decreases a large part of the uncertainty in valuing the put option. We believe that valuing and hedging such an option will become easier and absolute pricing differences between market prices and benchmark prices are likely to decrease.

Hypothesis 4: Issuers with a better rating charge higher premiums.

Both Hull (2006) and Reinmuth (2005) stress that financial institutions should adjust the value of a derivative for the counterparty credit risk. Higher premiums can be charged to compensate for higher credit risk. From the point of view of an investor, the relationship should also hold the other way around. In a functioning market, investors should be less willing to buy products from issuers with lower credit ratings if prices were equal. Structured products from issuers with a higher credit risk are thus expected to incorporate lower premiums in order to countervail the higher risk. Put differently, we expect that market prices exceed theoretical prices by more for issuers with a higher credit rating and by less for issuers with a lower rating.

Hypothesis 5: Products listed on the stock exchange comprise lower margins.

The market for structured products is often said to be nontransparent and issuers are accused to profit from this market opacity. Listing a product on the stock exchange is one method to increase the transparency in the market as it makes products more accessible and comparable. It seems reasonable to assume that issuers only list products that are at least adequately priced. Muck (2005) investigated the German market and found that OTC products were more expensive than listed products. We test the hypothesis for WBRCs on the Swiss market and expect that products listed on the stock exchange comprise lower margins.

Hypothesis 6: Products issued in collaboration with a marketing partner show higher pricing differences from the theoretical price.

Marketing partners or co-lead managers are smaller financial institutions willing to issue a structured product but unable or unwilling to do so on their own. They generally request a pricing from a number of different issuers and choose the one that best suits their needs. Wohlwend (2001) tested whether marketing partners do have a positive influence on the pricing of structured products and found evidence for more competitive pricings. However, besides the counter-intuitive result of more parties involved being cheaper we believe that the study is likely to be biased. In the analyzed dataset 89% of the products structured with a marketing partner were issued by two institutions only. We would expect that products involving more than one issuer generally are subject to higher premiums since both parties want to be compensated for their services. Contradictory to Wohlwend, we formulate the hypothesis that products issued in collaboration with a marketing partner show higher pricing differences from the theoretical price.

5 Data and methodology

For testing our hypotheses, we collected an extensive dataset of WBRCs issued on the Swiss market. This section explains how our data was gathered and adjusted and what methodology we used for verifying the hypotheses.

5.1 Data description

5.1.1 Data gathering procedure and sample

When structured products are issued, the issuing institution publishes a termsheet specifying the terms and conditions of the product. Our dataset was collected primarily from these termsheets. Starting from a complete list of the issuers on the Swiss market we went through each company's webpage in order to find the necessary data on the products. In case such overviews where not available on the issuer's page, we collected the termsheets from *dp payoff portal* and *scoach*. Even though such a procedure is very time consuming and still cannot guarantee the completeness of the entire products on the market, we found this to be the best approach to reach an extensive dataset of products issued on the Swiss market. Due to the opacity of the market, simply downloading the data from *dp payoff portal* or *scoach* would have resulted in a biased dataset that was far from being complete. We decided to limit our database to those WBRCs that had only Swiss underlying stocks, in order to avoid adjusting for exchange rate effects. Products denominated in CHF with non-Swiss underlying assets often include a currency protection (Quanto feature), an attribute that makes the valuation more complicated.

In the next step, we conducted the necessary adjustments for valuing the products. First of all, we controlled for corporate actions such as stock splits or special dividend payments. This is necessary as corporate actions change stock prices with retrospective effect and not all issuers adjust for this fact on their termsheets[7]. Correcting for corporate actions is important as the stock prices on the date of issuance of a WBRC are at the same time the strike levels of the option component for each underlying. Not adjusting for such actions would therefore lead to incorrect strike levels and make the valuation and comparison of such products inaccurate.

We then continued with collecting data that was not directly available from the termsheets. This is especially the case for the information whether the barrier has been touched or not, an information that is omitted by many issuers. By downloading the daily lows for all underlying assets from *Reuters* we controlled whether barrier levels were touched or not. As explained above, this is crucial information since the option component in the product is very sensitive to the barrier. The check needed to be done

[7] While not adjusting termsheets for corporate actions, without a doubt all issuers need to adjust the parameters in their trading systems.

on exactly the same day on which the products were priced. In the case of our dataset more than 62% of all barriers were touched.

The result of the above-described procedure is a unique dataset consisting of 976 WBRCs from 21 different issuers with about 25,000 data points. For the analysis and valuation of the products the dataset was limited to products with only three underlying assets. This is by far the largest group of products and can thus guarantee the unbiasedness of the data. As a further constraint we excluded all products containing underlying assets not included in the SMI. SMI stocks are the most liquid stocks on the Swiss market and structured products on such assets are likely to prove the highest comparability for different issuers.

5.1.2 Missing data and wrong information

The quality of information differs strongly between the financial institutions. While some issuers are very much inclined to provide the investor with complete information, others prove a lack of client orientation and information is rather difficult to obtain. This is most striking for the way products are quoted. For several issuers it was not specified whether products are quoted dirty or clean, i.e. whether the quoted prices include accrued interest payments or not. In case of such missing data we contacted the issuing institutions directly in order to collect the unavailable information. For several products it was however not possible to find the missing information and we therefore had to reduce the dataset by the respective products. The same held true for products with obviously incorrect information, such as wrong pricing dates. In total, we reduced the dataset by another 24 products.

We further performed cross-checks in order to verify the correctness of the dataset. Ensuring the correctness of the data is important since a large part of the dataset was collected manually. We focused our checks on the parameters that if incorrect would not make an obvious difference in the option price, but are nevertheless crucial for performing a sound analysis. Consequently, the maturity and coupon dates of the WBRCs were scrutinized whereas the underlying stocks for example were not as closely controlled since an error in the underlying would lead to a substantial difference in the option price. The procedure revealed minor errors in the dataset which we then corrected for.

5.2 Methodology

For the purpose of analyzing the factors and parameters influencing the pricing of WBRCs, we recalculated the products of the competitors by using the pricing model of EFG FP. Thereby we obtained the two pricing metrics theoretical price and benchmark price, which we compared to market prices. This approach of replicating the market price has been used in previous studies and is widely accepted. However, different from previous studies we made use of a professional pricing model that is as such applied on the market. This circumstance has enabled us to estimate the market prices more accurately and realistically, since there are considerable differences between pricing options with standard theoretical models and more advanced models that are specifically fitted to the real market conditions.

In order to conduct the analysis, we first had to obtain the market prices offered by the competitors. As the fixing date for the collection of market prices and the calculation we have chosen the 3rd of March 2008, an arbitrarily selected date. The market prices of WBRCs were retrieved from *Reuters*, where we took the closing ask prices of the day since they are more accurate than the last trading prices. The problem with last trading prices is that the majority of WBRCs are not frequently traded and thus last trading prices are often out of date. Bid and ask prices are frequently updated by the issuers throughout the trading hours and also at market closure. Hence, using ask prices improves the comparability of the sample. However, we could not retrieve all prices from *Reuters*, since *Reuters* does not quote many of the products not listed. The remaining ask prices were collected individually from *UBS Quotes* and if not available from the respective issuers' websites. Few products did not have updated bid and ask prices. We excluded all prices older than one hour from market closure, in order to ensure comparability. This was the case for 17 products.

After collecting prices, we fixed the input parameters of the EFG FP pricing model. Among them were the expected future dividends, various correlations between the underlying stocks and the parameters for the implied volatility surface. Fixing the input parameters was a necessary step since recalculating the products was a lengthy process. Also, it enabled us to calculate several different scenarios. By using the EFG FP model we first calculated the theoretical prices and thereafter the benchmark price.

5.3 Models and variables

In order to verify the six hypotheses we decided to use a regression-based approach. For this, we have constructed two econometric models. The regression models are explained in this section.

Regression model 1 looks as follows:

$$AbsDiffBench_i = \alpha + \beta_1 \cdot LifePassed_i + \beta_2 \cdot Knocked_i + \sum \beta_i \cdot Barrierdis\,dummies_i \qquad (7)$$

Variable	Type	Definition
AbsDiffBench	Dependent	The absolute value of the relative pricing difference between the market price and the benchmark price of a product.
LifePassed	Explanatory	Life of a product that has passed since product issuance. Measured in relative terms.
Knocked	Explanatory	Dummy variable which takes the value 1 if at least one of the underlying assets has touched the barrier level and 0 if the barrier level has not been touched.
BarrierDis	Explanatory	Dummy variables measuring the minimum of the distances of the underlying assets from the barrier level unless the barrier was knocked. Three different dummies: 0.00-0.05; 0.05-0.10; 0.10-0.15. BarrierDis >0.15 is the omitted group.

Table 3: Definition of variables for regression model 1

In model 1 the dependent variable is represented by the absolute value of the relative pricing difference between the market price and the calculated benchmark price of a product. In other words, the dependent variable measures the mispricing regardless of the sign. Formally, this can be written as follows:

$$AbsDiffBench_i = abs\left(\frac{Market\ price_i}{Benchmark\ price_i} - 1\right) \tag{8}$$

The absolute values are used because we want to measure the magnitude of price deviations of the estimated benchmark prices into either direction, i.e. it is not relevant whether market prices are lower or higher than the benchmark price but it is important to know by how much. *LifePassed, Knocked* and *BarrierDistance* serve as explanatory variables. *LifePassed* is expected to have a negative sign since we believe that absolute pricing differences are highest in the beginning of the product life and decrease towards maturity. The *Knocked* variable is expected to have a negative sign because the option component of the product should become easier to value once the barrier has been touched. The *BarrierDistance* dummy variables are expected to decrease in value as we move further away from the barrier.

Regression model 2 looks as follows:

$$\begin{aligned} RelDiffTheo_i = {} & \alpha + \beta_1 \cdot LifePassed_i + \beta_2 \cdot Listed_i + \beta_3 \cdot MarketingPartner_i \\ & + \sum \beta_i \cdot Rating\ dummies_i \end{aligned} \tag{9}$$

Variable	**Type**	**Definition**
RelDiffTheo	Dependent	The relative difference between the market price and the theoretical price of a product.
LifePassed	Explanatory	Life of a product that has passed since product issuance. Measured in relative terms.
Listed	Explanatory	Dummy variable which takes the value 1 if the product is listed on the stock exchange and 0 if the product is not listed.
MarketingPartner	Explanatory	Dummy variable which takes the value 1 if the product was issued in collaboration with a marketing partner and 0 if there is no marketing partner.
Rating	Explanatory	Dummy variables for each of the represented rating classes. Using the rating classes for Moody's long-term credit rating, we have five different dummies: Aaa; Aa1; Aa2; Aa3; A1. *Not rated* is the omitted group.

Table 4: Definition of variables for regression model 2

In model 2 we use the relative differences between the market price and the theoretical price of a product as the dependent variable. Formally, this can be written as follows:

$$RelDiffTheo_i = \left(\frac{Market\ price_i}{Theoretical\ price_i} - 1\right) \tag{10}$$

The explanatory variables are *LifePassed*, *Listed*, *MarketingPartner* and *Rating*. *LifePassed* is introduced in order to avoid a model specification error since it is intuitive that margins are reduced over time. *Listed* is expected to have a negative sign, since we believe that margins are lower for listed products. *MarketingPartner* is expected to have a positive sign as we suppose that products issued in collaboration are likely to comprise higher premiums. Finally, the *Rating* dummy variables are expected to decrease in value as we move further away from the *Aaa* credit rating, because we believe that a better rating should be a reason for customers to pay higher premiums.

6 Empirical findings and analysis

In this section, we will show and discuss the results obtained by our analysis. In particular, we focus on our six hypotheses and show whether our findings can contribute to supporting our hypotheses.

6.1 Descriptive statistics

Issuer	Mean	Stdev	Min	Max	Number
Clariden Leu	–0.27%	1.51%	–4.79%	2.84%	79
Goldman Sachs	0.35%	1.43%	–3.80%	3.50%	62
Vontobel	–0.79%	1.81%	–5.24%	2.39%	60
UBS	0.74%	1.51%	–2.87%	2.59%	47
Julius Baer	0.80%	1.46%	–3.71%	3.13%	36
Sarasin	–0.02%	2.49%	–4.14%	6.25%	29
ZKB	–0.66%	1.61%	–4.85%	3.41%	29
BCV	–0.65%	1.77%	–3.96%	3.61%	22
JP Morgan	0.39%	1.24%	–2.46%	2.06%	20
Credit Suisse	0.00%	1.75%	–2.30%	3.44%	13
Merrill Lynch	–0.61%	1.75%	–3.45%	2.19%	11
Societe Generale	–1.79%	2.58%	–5.17%	0.81%	7
Sal. Oppenheim	–0.13%	1.59%	–2.35%	1.68%	5
Gottardo	1.50%	2.44%	–1.39%	3.88%	4
BNP Paribas	–2.64%	2.64%	–4.59%	0.36%	3
Deutsche Bank	2.86%	3.97%	0.05%	5.67%	2
Dresdner Kleinwort	0.74%	0.22%	0.58%	0.89%	2
HSBC	–1.71%	2.11%	–3.20%	–0.22%	2
Natixis	–2.54%	N/A	–2.54%	–2.54%	1
Total	**–0.07%**	**1.80%**	**–5.24%**	**6.25%**	**434**

Table 5: Descriptive statistics by issuing institution
The mean denotes the average pricing difference of quoted market prices from the benchmark. A negative mean implies that the issuer is cheaper compared to the benchmark and a positive mean implies that the issuer is more expensive compared to the benchmark.

The market for structured products in Switzerland is very much developed and a large number of market players are present. This is also represented in our dataset. It includes 19 different financial institutions issuing in total 434 WBRCs. Nine institutions make up for 88% of the analyzed products. While the dataset does not picture the market environment perfectly, it still shows the important issuers for WBRCs. As such, we should mention Clariden Leu, Goldman Sachs, Vontobel, UBS, Julius Baer, ZKB, Sarasin, BCV and JP Morgan.

Looking at the pricing differences from the benchmark, it is interesting to note that there is on average a very small pricing difference of –0.07%. The most expensive product issuer is Deutsche Bank by far. Since the sample includes only two products the number is however not very meaningful. Only considering the nine largest samples, Julius Baer is the most expensive one. On the other hand, the cheapest institution among the large issuers is Vontobel with a mean pricing difference of –0.79%.

The standard deviations range from 0.22% to 3.97%. With decreasing sample size, the standard deviations generally increase. This is probably due to a non-satisfactory sample size. Minimum and maximum pricing differences range between –5.24% and 6.25%. Higher negative deviations would be surprising since this could imply arbitrage opportunities

6.2 General results

We first want to look at the pricing differences from the nine largest samples. They can be read from the figure below:

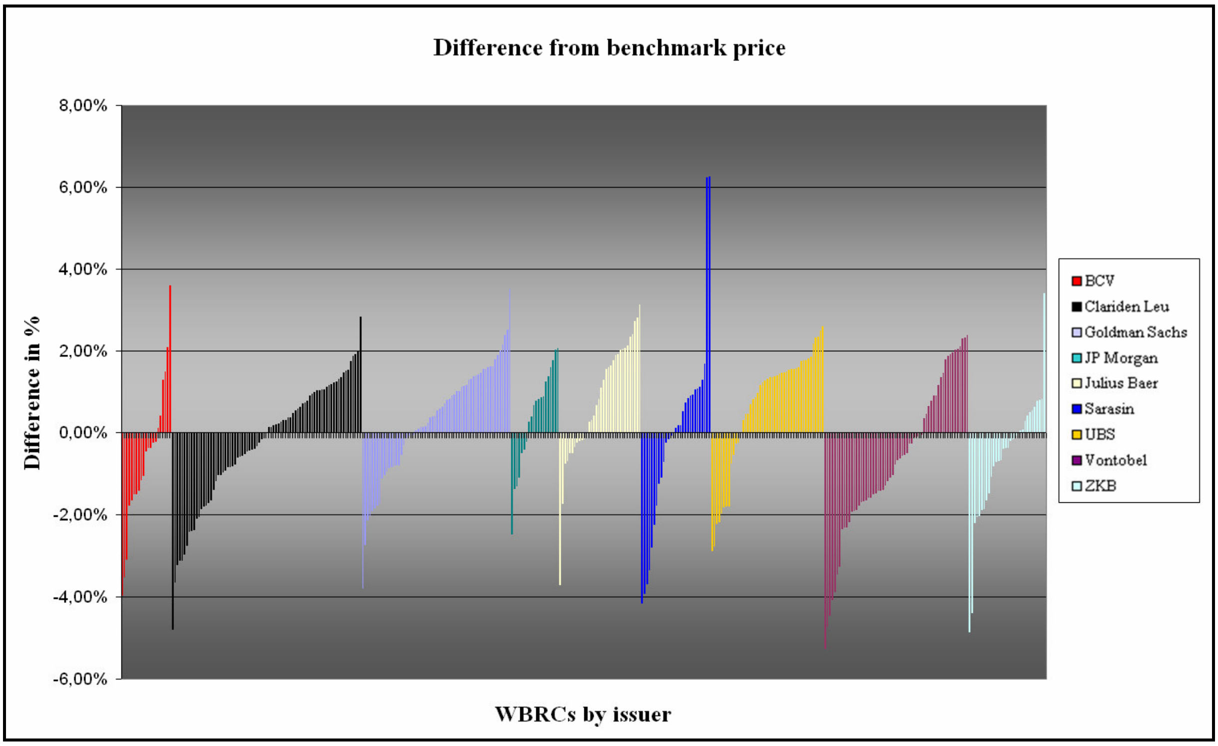

Figure 5: Pricing differences from benchmark by issuer

Figure 5 emphasizes the outcome of the descriptive statistics. The prices of Julius Baer, which has been found to be the most expensive issuer, are almost always above the benchmark prices. Very few products are priced below the benchmark. Contrariwise Vontobel, which has been found to be very competitive in relation to benchmark prices, shows a large number of negative differences but also several small positive differences. The pricing scheme being most similar to the benchmark appears to be the one by JP Morgan. Throughout all products we find small differences into either direction. From the descriptive statistics we can see that the mean difference is only 0.39% higher and the standard deviation is 1.24%, which is the lowest of all large samples.

From the descriptive statistics we can further see that the standard deviations of the pricing differences among the large samples are between 1.24% and 1.81%, with the exception of Sarasin which has a standard deviation of 2.49%. This high standard deviation can be an indication that Sarasin calculates their products with a very different model from what we used whereas the pricing models applied by other competitors are somewhat similar. Also, it is probable that Sarasin does not structure its products on its own being a small private bank. This would then explain the rather inconsistent pricing. Figure 6 below emphasizes the large differences of Sarasin's market prices from the benchmark price.

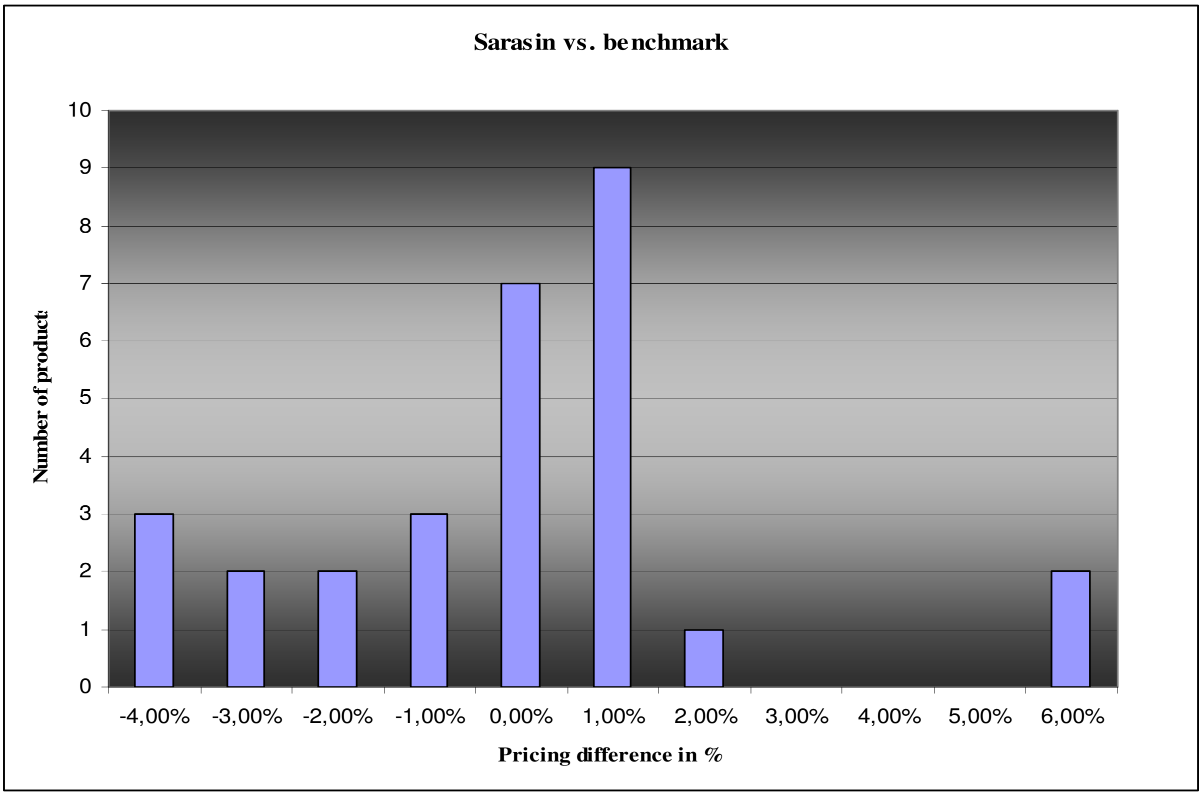

Figure 6: Comparing pricing differences of Sarasin vs. benchmark

With regards to differences from theoretical prices, it is notable that these differences are on average small. In our dataset we find only 19 products exceeding a premium of 3%. This is surprising since WBRCs are rather complex products and previous studies have shown that complex products are likely to comprise higher margins (Stoimenov & Wilkens, 2004). It seems as though the increasing number of market participants enhances the market efficiency and leads to declining margins even for complex investment products.

6.3 Model 1 – Precision analysis

In the following the output of model 1 will be discussed[8]. It is important to understand that all explanatory variables in model 1 were designed in order to explain absolute differences between quoted market prices and the benchmark calculation.

Model 1 looks as follows:

$$AbsDiffBench_i = \alpha + \beta_1 \cdot LifePassed_i + \beta_2 \cdot Knocked_i + \sum \beta_i \cdot Barrierdis\,dummies_i \qquad (11)$$

[8] The output of the regression is shown in appendix A.

The most significant influence factor is *LifePassed*, i.e. the percentage of life that has been passed since the product origination. With a beta of –0.008, both the sign and the magnitude are as expected. Thus, there is no reason to reject hypothesis 2. Absolute pricing differences seem to decrease as we move further towards maturity. Even though we did not analyze products at maturity, we would expect that pricing differences between different issuers for the same product approach zero at the end of the product life.

Further significant is the *Knocked* variable. The hypothesis was that products for which one or more of the assets have touched the barrier level are priced more consistently. Hence, we expected the sign of the *Knocked* variable to be negative. The regression shows a beta of –0.344 for the *Knocked* variable which is significant at the 5% level. This is broadly in line with our expectations, i.e. less complex options are easier to value and thus show lower absolute pricing differences from one issuer to the other. There is evidence for a more consistent pricing between the issuers once the barrier level has been touched.

Looking at the dummy variables for the *barrier distance*, it becomes obvious that none of them is significant at a reasonable confidence level. Neither are the beta values according to our expectations. The hypothesis was further tested with a numerical implementation but the results do not change. Thus, we have to reject hypothesis 1. There seems to be little evidence that the distance of the underlying assets from the barrier level influences the mispricing into either direction. This result indicates that the pricing models used by different issuers are similar. In particular, it is a sign of all issuers working with local volatility or stochastic volatility models (Pätzold, interview on 17/03/2008). Models using constant volatility would generate more deviating results especially when the underlying assets trade close to the barrier.

6.4 Model 2 – Pricing analysis

We will now discuss the regression of model 2[9]. The model was designed so that potential sources of differences from the theoretical price can be measured.

Model 2 looks as follows:

$$\begin{aligned} RelDiffTheo_i = {} & \alpha + \beta_1 \cdot LifePassed_i + \beta_2 \cdot Listed_i + \beta_3 \cdot MarketingPartner_i \\ & + \sum \beta_i \cdot Rating\ dummies_i \end{aligned} \tag{12}$$

The output from the regression is rather disappointing and does not show a clear picture. The explanatory power of the model is low and conclusions are hard to draw. Except for the *LifePassed* variable and one of the rating dummies, all variables are insignificant at the 10% level. The model can certainly not be used to describe the relative differences from the theoretical price. Nevertheless, we

[9] The output of the regression is shown in appendix A.

will discuss the hypotheses with the respective variables and look for reasons which could explain the failure of the model.

Hypothesis 5 stated that products listed on the stock exchange show lower pricing differences. Thus, we expected the sign of the *Listed* variable to be negative. While the sign is as expected, it has a p-value of as high as 0.286. This is clearly insignificant. One potential source why we can not find a relationship of listed products on the pricing difference is that we are looking at secondary market products only. It is possible that this blurs the effect of a more adequate pricing of listed products despite introducing the *LifePassed* variable. While the relationship may have existed at the time of issuance it might have disappeared since then. In order to test for this, one should consider product prices at issuance and run the regression once more. Unfortunately, with the system in place we are unable to conduct such an analysis. From the results given, we have to reject the hypothesis and conclude that there is no significant evidence of listed products being priced more adequately.

In hypothesis 6 we tested whether marketing partners are a source for higher differences from the theoretical price. The hypothesis was that more parties involved in the product development would lead to an increase in pricing since both the issuer and the marketing partner want to be compensated for their services. Beta was expected to be positive. The regression shows a beta for *MarketingPartner* of 0.421 with a p-value of 0.139. Similar to the *Listed* variable, the sign is as expected but the significance level is not satisfactory enough. The value is too low in our opinion so that we reject hypothesis 6. We are not able to find that product issued with a marketing partner are significantly more overpriced. A possible explanation for the lack of significance is given by Baumann (interview on 06/03/2008). While both parties want to be compensated for their services there is an opposing effect on the pricing at the same time. Marketing partners request pricings from several issuers and choose the one that best suits their interests. Generally, this is the best price. Therefore, even though marketing partners want to earn a certain percentage for themselves, prices are likely to be at the industry average or even lower.

The regression results for the *rating dummies* are not more promising. Four out of five rating classes are not significant at the 10% level while only the Aa3 rating shows a high significance level. Concerning the beta, we expected a decreasing number moving towards a lower rating, i.e. we expected that products from issuers with a better rating contain higher premiums. This effect is not visible and leads us to reject hypothesis 4. There seems to be no clear effect of credit ratings on product prices. Potential reasons for our hypothesis not to hold are various. It is possible that investors do not factor ratings into their investment decision because products are simply too complicated for them to do so. Further, it is conceivable that investors do not believe it to be necessary since all ratings are in a rather close range or because credit ratings are not considered to be meaningful for products with short maturities. Finally, there is the possibility that the effect has disappeared because we analyze only products on the secondary market. As mentioned above, we are not able to test for this with the approach applied in our study.

Summary of results

Table 7 below summarizes the results of our study. We find that two of our hypotheses hold while we cannot find significant evidence for the other four.

Hypothesis		Support
H_1	*Products with underlying assets trading closer to the barrier level show higher absolute pricing differences.*	No
H_2	*Absolute pricing differences decrease with time.*	Yes
H_3	*Products where one or more of the underlying assets have touched the barrier are priced more consistently.*	Yes
H_4	*Issuers with a better rating charge higher premiums.*	No
H_5	*Products listed on the stock exchange comprise lower margins.*	No
H_6	*Products issued in collaboration with a marketing partner show higher pricing differences from the theoretical price.*	No

Table 6: Summary of results of hypothesis testing

7 Concluding remarks

This study investigates the valuation of structured investment products with embedded exotic options on the Swiss market. During a three months project at EFG Financial Products in Switzerland, we have recalculated and analyzed 434 Worst-of Barrier Reverse Convertibles on SMI underlying stocks. Using a professional pricing model, we both calculate the theoretical value of the products and estimate the market value that EFG FP would offer in order to use this as a benchmark. We then compare these prices with the market prices offered by the competitors. By employing a regression-based approach, we look at factors that can explain pricing differences between market prices and benchmark prices. Moreover, we try to find factors that are potentially liable for the deviations from the theoretical price.

With regards to the pricing differences between the institutions, we find that they are generally small. On average, market prices differ by only –0.07% from the benchmark prices that we calculated and standard deviations are low. This indicates that issuers use similar valuation models even for complex products and that the Swiss market is quite developed and competitive. Two factors are likely to increase the pricing consistency between different issuers. First, WBRCs where one or more of the underlying assets have touched the barrier level show lower pricing differences. Second, pricing differences decrease with declining time to maturity. In both cases, we believe that the option component is becoming easier to value as the uncertainty decreases and therefore leads to a more consistent pricing. With regards to differences from the theoretical price, the results we obtain are not significant. We do not find any evidence that either a marketing partner, the issuer's rating or the fact that the product is listed on the stock exchange influence the competitiveness of pricing.

This master thesis pursued to deliver a better understanding of the valuation of structured products. We believe that our results have provided valuable input for the ongoing discussion on the structured products market. Our results indicate that the market has continued to converge with low pricing differences even for very complex products. Nevertheless, the difficulties in obtaining significant determinants for the differences from the theoretical price imply that products are still much too complex for the ordinary investor to compare. This could serve as an explanation why credit ratings or listings do not seem to have any effect on the pricing.

7.1 Further research

Structured investment products have become increasingly important in Switzerland and across Europe and we strongly believe that the trend will continue in the near future. While many articles and opinions have been written, only few address the topic from a scientific angle. Because of its importance for today's investment decisions of both individuals and institutional investors we feel that more research on structured products would be of great value. During the writing process we have come across numerous topics on which further research could be done. We here present only a selection of ideas.

In our study on Reverse Convertibles we have focused on products with the worst-of feature. While being one of the most important products on the market, it is only one out of many on which research should be done. Especially new products are likely to reveal new and interesting information. For example, during our project in Switzerland the Multi Chance Barrier Reverse Convertible was invented. While being similar in many parameters, it is a very different product in terms of dependency on the underlying assets' correlations.

We further welcome any research aiming for increasing and strengthening the transparency in the structured products market. As such, we have in mind studies that analyze similarities and differences between products, issuers and markets. In particular, we would welcome a study comparing the different markets in Europe such as Germany, Sweden, Switzerland, etc. It would be interesting to see whether there are regional differences regarding investment behaviors and how much the markets are actually influenced by the respective legal and tax systems.

Finally, further research could analyze structured products from an investment perspective. Structured products offer a great range of opportunities to an investor. It is possible that such products can be used to improve existing investment strategies. Little research has been done on this topic. Also, studies on the long-term performance of structured products are likely to improve the investor's awareness of return and risk measurements.

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9 Appendix

A) Regression output

Model 1: Dependent variable: AbsDiffBench

Variable	Coefficient	Significance	t-statistic
(Constant)	2.018	0.000	16.536
LifePassed***	–0.008	0.002	–3.082
Knocked**	–0.344	0.020	–2.340
Bdis 0.00-0.05	–0.184	0.662	–0.438
Bdis 0.05-0.10	0.170	0.592	0.537
Bdis 0.10-0.15	0.008	0.974	0.032
No. of observations	434		
R^2	0.089		
Adjusted R^2	0.078		
F	8.313		
F significance level	0.000		

Significant at 1% (***), 5% (**) and 10% (*) level.

Model 2: Dependent variable: RelDiffTheo

Variable	Coefficient	Significance	t-statistic
(Constant)	0.303	0.304	1.029
LifePassed***	–0.009	0.005	–2.827
Listed	–0.237	0.286	–1.069
MarketingPartner	0.421	0.139	1.482
Aaa	0.313	0.149	1.444
Aa1	–1.158	0.113	–1.590
Aa2	0.131	0.742	0.330
Aa3***	0.908	0.000	4.059
A1	–0.314	0.341	–0.951
No. of observations	434		
R^2	0.057		
Adjusted R^2	0.040		
F	3.237		
F significance level	0.001		

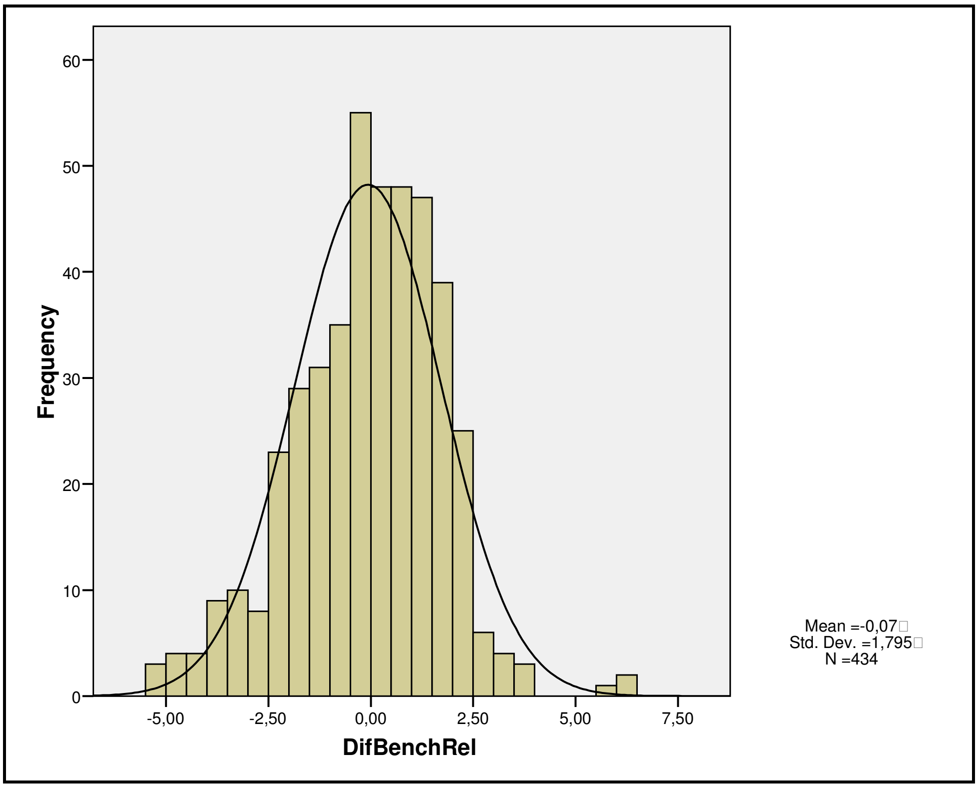
Significant at 1% (***), 5% (**) and 10% (*) level.

B) Descriptive statistics of marketing partners

Issuer	Mean	Stdev	Min	Max	Number
No marketing partner	–0.06%	1.79%	–5.24%	6.25%	391
Valiant	–1.17%	2.32%	–4.59%	2.40%	10
VP Bank	0.00%	1.00%	–1.49%	1.15%	5
Alpha Rheintal Bank	–0.09%	1.62%	–2.29%	1.58%	4
Gestofin PA Christinat	0.02%	0.30%	–0.23%	0.41%	4
St. Galler KB & Hyposwiss Privatbank	0.59%	2.76%	–2.54%	3.61%	4
Bank Thalwil	1.52%	1.87%	0.19%	2.84%	2
Basellandschaftliche KB	–0.19%	2.83%	–2.19%	1.81%	2
Raiffeisen Schweiz	–0.01%	3.25%	–2.30%	2.29%	2
St.Galler KB	2.13%	0.36%	1.88%	2.39%	2
Aargauische KB	–1.88%	N/A	–1.88%	–1.88%	1
Bank CA St.Gallen	1.04%	N/A	1.04%	1.04%	1
Bank Coop	–1.09%	N/A	–1.09%	–1.09%	1
Bank Linth	–0.06%	N/A	–0.06%	–0.06%	1
Liechtensteinische Landesbank	2.01%	N/A	2.01%	2.01%	1
Luzerner KB	–1.65%	N/A	–1.65%	–1.65%	1
Migrosbank	–0.99%	N/A	–0.99%	–0.99%	1
Thurgauer KB	–0.25%	N/A	–0.25%	–0.25%	1
Total	**–0.07%**	**1.80%**	**–5.24%**	**6.25%**	**434**

The mean denotes the average pricing difference of quoted market prices from the benchmark. A negative mean implies that the marketing partner is cheaper compared to the benchmark and a positive mean implies that the marketing partner is more expensive compared to the benchmark.

C) Distribution of differences from benchmark



D) The Greek letters (Chriss, 1997)

Greek letter	Symbol	Meaning
Delta	Δ	The rate of change of the value of an option with respect to changes in the stock price.
Gamma	Γ	The rate of change of the delta with respect to changes in the stock price.
Theta	Θ	The rate of change of the value of an option with respect to time.
Rho	ρ	The rate of change of the value of an option with respect to the risk-free rate of interest.
Vega	υ	The rate of change of the value of an option with respect to volatility.