The long-term consequences of internal asymmetry for corporations exposed to exchange rate risk

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Title of thesis:
The long-term consequences of internal asymmetry for corporations exposed to exchange rate risk

Abstract:
A company exposed to foreign exchange rate risk suffers from asymmetric internal effects which cause the company to gradually lose value compared to a company not exposed to the risk. This holds true even if the exchange rate risk were perfectly symmetric. The long-term effects of internal asymmetries, defined here as concavity in investment profitability, convexity in external financing and convexity in taxation, are examined by running a Monte Carlo simulation on a fictitious company exposed only to currency risk.

The results, which show strong resilience to robustness tests, indicate that hedging against symmetric exchange rate risk both statistically and economically significantly improves company performance. Furthermore, the results strongly suggest that a company runs suboptimally when hedging the risk with non-linear hedges compared to a company using linear hedges.

This paper contributes to the existing academic work on exchange rate risk by studying the long-term perspective - something widely neglected in the field. The results shed new light into the debate and bring forth evidence that non-linear hedges leave companies partly exposed to internal asymmetries and thus weaken company performance compared to linear hedges.

Keywords:
Foreign exchange, currency risk, Monte Carlo, derivatives, hedging, corporate finance, simulation, options, forwards, risk
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1 INTRODUCTION

The late 2014 events in Ukraine and the Swiss National Bank’s decision to remove the EURCHF peg served as good reminders of the potential risks in foreign exchange. Exporters in Russia saw their sales melt as rouble traded above 100.00 against euro in December 17th compared with 48.75 roughly 3 months earlier. Similarly the 29% intraday crash in EURCHF left many Swiss companies effectively in turmoil within minutes.¹ When the potential risks are combined with the astronomical size of the market - USD 5.3 trillion daily average volume in April 2013 according to the Bank for International Settlements (2013) - it becomes understandable why the topic of hedging exchange rate risk has been studied and debated intensively (Investment setting: Glen & Jorion (1993) and Black (1990), Corporate setting: Stulz (1984), Breeden & Viswanathan (1998) and Lessard (1990)).

Today, all companies, even those not directly involved in foreign trade, are to some extent subject to exchange rate risk. If a company doesn’t conduct major operational changes termed as on-balance sheet hedges to mitigate the risk it has three basic alternatives: The company can choose to neglect the risk or hedge it using either linear or non-linear contractual hedges. The academic literature is heavily weighted towards comparing contractual hedges to remaining unhedged and comparing the two subcategories of contractual hedges against each other. The discussion is focused on external issues such as external performance reporting or competition (e.g. Adam, Gasgupta & Titman 2007) and few articles (e.g. Froot, Scharfstein & Stein 1993) discuss the effects of exchange rate risk within the companies. Furthermore, the topic has hardly been touched upon in the long-term setting, which one could argue is the most relevant for companies who aim at running into the foreseeable future - going concern.

This paper contributes to several strands of the literature and the ongoing debate of hedging exchange rate risk. First, it studies the internal effects of foreign exchange rate risk in the long-term perspective and sheds light into the accumulation of risk over time. Second, it monetizes the value of internal asymmetries in a company when faced with exchange rate risk.

¹ Author's own calculations, data source: Bloomberg
Lastly and most importantly, it discovers internal asymmetry based argumentation against the use of non-linear hedges in companies. The argumentation against the use of non-linear hedges based on internal asymmetries has not been brought forward in academic literature related to exchange rate risk before this paper.

Anecdotal evidence implies that in the long run exchange rate risk cannot affect a company as exchange rates tend to be mean-reverting and have relatively short cycles (3-7 years). The idea for this line of argument is that exchange rates will cut profits some years and boost them the other averaging each other out in the long run. While the basis of the argument, i.e. the mean-reverting character, might very well hold true (Dimson, Marsh & Staunton 2012), it is not quite so straightforward that the risk is symmetric for corporations.

For buy-and-hold debt and equity investments it can be shown that in the (very) long run exchange rates play a minor role due to their long-run stability (Dimson, Marsh, Staunton, 2012). But the major difference between direct investments and running a company is that there are a multitude of asymmetries within the company that cause it to lose more when there is an unfavourable movement than it wins when there is a favourable one of equal size.

The asymmetry arises mainly from the inability to take on infinitely many equally profitable investments, from the convex or even progressive nature of taxation and asymmetric costs of external financing. To put it simply, even if variability in cash flows were symmetric and were mean-reverting, it does affect how the company works as a machine.

This paper examines the long-term consequences of foreign exchange risk by simulating the value and performance of a simplified pro forma company exposed only to exchange risk. The company logic is largely based on generalized accounting rules and a set of rational managerial decisions that aim at maximizing shareholder value.

The paper concentrates on the differences between hedging currency risk with linear contracts (represented by forward contracts), hedging it with non-linear contracts (represented by options) and not hedging at all. This paper brings continuity of business or *going concern* thinking along and brings up empirical evidence that hedging with non-linear contracts might be suboptimal for companies when only considering the company in isolation from its competitors and customers.
The results of the empirical study imply that three major sources of asymmetry, the inability to take on infinitely many equally profitable investments, inability to fully offset profits and losses in taxation and the transaction and information asymmetry related costs of external financing are enough to cause economically significant performance differences between companies who hedge with forwards, those who hedge with options and those who do not hedge at all. The non-linearities disrupt the company which remains unhedged the most, but affect even the company which uses options. The results are mainly driven by asymmetric external financing and concave investment opportunities, while surprisingly being much less affected by tax asymmetry.

The results are robust to assumptions made regarding the company and the simulation of currencies. Despite the fact that the assumptions are shown to be conservative the economic significance of the results is still beyond debate.

To the best of my knowledge no articles have been published where arguments have been given against the use of options in hedging due to the asymmetry of the overall functioning of the company. This article sheds new light into the already intensive discussion and helps companies make the decision between hedging strategies.
2 PURPOSE, RESTRICTIONS AND RESEARCH HYPOTHESES OF THE THESIS

This chapter serves to explicitly state the purpose and restrictions of the study and to introduce the research hypotheses.

2.1 Purpose of the study

The purpose is to examine and numerically measure how internal asymmetry in a company can affect the company's performance when facing foreign exchange risk and study what are its implications on the performance of different hedging alternatives in the long run.

2.2 Restrictions

The foreign exchange risk will be restricted to committed and anticipated transaction risk. Economic risk defined broadly as long-term strategic foreign exchange risk will be excluded due to general problems in defining the risk and specific problems in measuring it. Translation risk will be excluded due to the indirect nature in which it affects companies and the different technique in which it is hedged.

The comparison of contractual linear and non-linear hedges are restricted to forward contracts and European style options with a 100% hedge ratio.

Throughout the rest of the study the research question will be devoted on the corporation's view. So, any use of argument refers to the corporation's view as opposed to a perspective of a financial institution.

Since the topic will be examined through a Monte Carlo simulation a myriad of assumptions have to be introduced. These restricting assumptions are discussed in more detail in section 7.
2.3 Research hypotheses

*Hypothesis 1:* Inability to take on infinitely many equally profitable investments, inability to fully offset profits and losses in taxation and the transaction and information asymmetry related costs of external financing will cause a company exposed to foreign exchange rate risk to lose money in the long run even if the exchange rates were *on average* constant.

*Hypothesis 2:* Given the inability to take on infinitely many equally profitable investments, inability to fully offset profits and losses in taxation and the transaction and information asymmetry related costs of external financing, hedging with non-linear products is suboptimal compared to hedging with linear products as non-linear hedges retain part of the exposure to internal asymmetry yet exposing the company to the full premium cost of the non-linear hedge.
3 PRIMER TO EXCHANGE RATE RISK THROUGH THE LENS OF A CORPORATION

A corporation is, while operating, exposed to a number of different categorical exchange rate risks. First, there is transaction risk which refers to contractual or expected foreign currency dominated sales and purchases. Second, there is translation risk which refers to balance sheet currency risk arising from the consolidation of balance sheet items denoted in different currencies. Lastly, there is economic or operating risk, which covers the rest. However, no clear cut definitions have been made and translation risk - while not well recognized by companies - is perhaps the best defined of the three.

3.1 Transaction or contractual risk

Transaction risk could simply be described as the risk arising from committed foreign currency denominated sales and purchases due to changes in the exchange rate between the foreign and domestic currency. Transaction risk is generally well recognized and appreciated in companies because it is easy to measure and, perhaps more importantly, because it shows up directly in the company’s cash flows.

A simple example would be a euro area company which sells its products in the United States in US dollars on credit. In this case the Euro area company commits to a US dollar valued sale at time \( T_0 \) and is due to receive payment at date \( T_1 \). Since the dollar amount is fixed during the time between \( T_0 \) and \( T_1 \) the company is exposed to foreign exchange risk for that individual sale.

A numerical example is provided in Table 1, where a euro area company sells its products for USD 500,000 in the United States (or anywhere else for that matter). In the beginning the committed sale is approximately worth EUR 385,000 when the exchange rate is at 1.3000. But as time goes by the US dollar weakens against euro and the sale is only worth EUR 370,000 when the payment is received. This causes a EUR 15,000 loss for the exporting company - compared with \( T_0 \) value.

---

2 Foreign and domestic currency meaning home and foreign country currency in a geological sense. Should not be confused with the convention in foreign exchange where rates are quoted as FORDOM [e.g. EURUSD], where foreign and domestic do not in any way refer to a geological location.
<table>
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<th>(T_0)</th>
<th>(T_1)</th>
<th>Difference</th>
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<td>USD valued sale</td>
<td>USD 500,000</td>
<td>USD 500,000</td>
<td>USD 0</td>
</tr>
<tr>
<td>EURUSD</td>
<td>1.3000</td>
<td>1.3500</td>
<td>500 pips³</td>
</tr>
<tr>
<td>EUR valued sale</td>
<td>EUR 385,000</td>
<td>EUR 370,000</td>
<td>EUR -15,000</td>
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Table 1  **Transaction risk:** A dollar valued sale (top row) may lose value in euro terms (bottom row) if there is an unfavourable exchange rate movement.

### 3.2 Translation or accounting risk

Translation risk shows up on a company’s *consolidated balance sheet* when foreign currency denominated assets and liabilities are brought together with the home currency valued counterparties. Since it doesn’t show up directly in the company's cash flows its effects are more difficult to evaluate. Anecdotal evidence suggests that companies are clearly less concerned with translation than transaction risk, which may follow from the difficulty to evaluate it.

Translation risk works indirectly through variation in financial ratios which themselves can affect company valuation, risk perception, financial covenants and performance follow-up. All these problems can be opened through a simple numerical example: A corporation consists of a parent company whose assets and liabilities are all in euro and a foreign subsidiary whose liabilities are in euro but assets in US dollars. When the company reports its financials at the end of the year the balance sheets are consolidated at the parent company level. The US dollar denominated foreign subsidiary assets get translated into euro and any changes in the exchange rate get reflected in the consolidated balance sheet.

Figure 1 shows that if the US dollar depreciates from 1.3000 to 1.3500 against euro the consolidated equity drops from EUR 281m to EUR 272m. Similarly the debt-to-equity ratio goes from 1.60 to 1.65. These changes would have been more pronounced had the US dollar denominated assets in the foreign subsidiary or the exchange rate changes been larger.

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³ Price interest points, in EURUSD 1 pip = 1 / 10000
The example shows how the (book) value of equity drops as a result of the exchange rate change. The company also becomes more leveraged if measured as book debt/equity. The fact that the company becomes more leveraged may trigger debt covenants which restrict the indebtedness of the corporation and change the risk perception of investors. It can also make performance follow-up more difficult as part of the performance gets eaten by unfavourable movements in the exchange rate. The problem is visible both in the consolidated and the foreign subsidiary’s balance sheet.

**Figure 1**  Translation risk: A company’s consolidated balance sheet is affected by changes in home currency valued assets and liabilities in the subsidiary. Dashed line separates scenarios 1 and 2 where the EUR/USD exchange rate is 1.3000 and 1.3500, respectively.

### 3.3 Economic or operating risk

Separating economic risk from transaction risk is not always quite straightforward. According to some definitions transaction risk relates to *committed* transactions while economic risk relates to other exchange rate risks which have a cash flow effect. This would include *expected* transactions which the company has not yet committed to.
Some definitions separate between *committed* and *expected* transaction risk leaving other exchange rate risks with a cash flow impact into economic risk. Still other definitions take a time perspective approach. The last approach would consider short-term variations to be transactional and long-term *level changes* to have an economic impact. The topic is discussed in Adler and Dumas (1984).

Despite some overlap in the definitions of economic and transaction risk there is one situation where all definitions agree that risk is clearly economic and not transactional. This is when a domestic supplier ($S_d$) competes with a foreign supplier ($S_f$) of another domestic company's purchases (domestic Demand, $D_d$). In this case $S_d$ does not have a direct transaction risk as it always sells its products in home currency. The exchange rate risk arises from competition as $S_f$ might be able to sell its products of equal quality at a lower price due to a favourable exchange rate. As one can see, neither the committed nor expected transactions of the $S_d$ have exchange rate risk - yet its cash flows are threatened.

Economic risk - if not purely defined as expected transactions - is often difficult to hedge against using contractual instruments. If for example a Euro area company has production within the area but sales in the United States it competes with US firms which have production there. If there is an unfavourable level change in the exchange rate it might force the Euro area company to retrieve from US markets or shift production on the other continent. Level changes are in practice impossible to hedge against using contractual instruments.
4 WAYS OF HEDGING FOREIGN EXCHANGE RISK

A company has four basic alternatives with respect to handling transactional exchange rate risk. The first alternative is not to hedge at all and hope for the best. Not hedging can be implemented either using a cash buffer or not. Although not a hedge per se, a cash buffer does mitigate the effects of unfavourable exchange rates. If the company decides to hedge it can either do so using linear (e.g. forwards) or non-linear (e.g. options) off-balance sheet hedges. In addition to these four alternatives a company can also implement something termed as operative or on-balance sheet hedges but as they often alter the very business of the company they are not discussed in this context. In the following each alternative is explained in more detail.

4.1 Cash buffer

If a company is subject to cash flow variation and it wishes to reduce the impact of this variation to its investment opportunities or financing decisions it can simply hold a cash buffer. Financial slack in the form of cash or marketable securities gives the company ability to dampen any external variations before making costly decisions to increase external financing or to cut investments.

As such it sounds like a right-under-one's-nose solution to all problems caused by external risk but holding cash entails an alternative cost which at times can be very significant. The shareholders of the company are often strongly against excessive cash buffers as the money could be invested elsewhere. Also, as discussed in section 5.5.3, financial slack can have an effect on managerial behaviour in the form of wasteful investment, empire building and excessive perks.

As such using a large cash buffer might very well be more costly for a company than using financial hedges, many of which do not entail any direct costs.

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4 Interestingly enough, during the process of writing this thesis the alternative cost was at times negative as real interest rates were unusually low across the majority of developed European countries
4.2 Linear contractual hedges

The most common linear hedges are forward and futures contracts. Since foreign exchange is mainly an OTC market the vast majority of linear hedges are forward contracts.

A forward contract is an agreement to buy or sell an underlying asset at a certain future time for a certain price. An example of a forward contract would be for A to agree to sell EUR 100 million for US dollars in a year with a price of EURUSD=1.3000 and for B to agree to the opposite. Once set, the price of the future trade can no longer change for the two counterparties - no matter what the future spot level.

Forward contracts are usually set at a level which makes the contract initially zero cost. The level is determined exactly with a no-arbitrage argument with the following formula:

\[ F_t = S_t \times e^{(r_d-r_f)\times T}, \]

where \( S_t \) is the current spot, \( r_d \) and \( r_f \) the domestic and foreign risk-free rates and \( T \) is time to maturity.

In foreign exchange forwards (and options too) are particularly good in the sense that the underlying asset of the contracts often matches 1-to-1 with the risky asset and the exercise date can be set exactly to the date of the cash flows (provided they are known in advance). In hedging jargon the basis risk is small in FX. This can be contrasted with hedging kerosene risk in the flight industry: As kerosene itself is not liquidly traded it must be hedged with a proxy hedge (for example Brent oil), whose price changes do not match perfectly with kerosene. If hedging is done on exchange traded futures contracts whose expiry dates do not match those of the cash flows the basis risk is increased.
4.3 Non-linear contractual hedges

Non-linear hedges cover all financial instruments whose payoffs are not linear. Fischer Black once said that if you can draw a payoff pattern on paper or describe it in words, someone can design a derivative that gives you that payoff. It means that the array of different non-linear products and strategies is endless. For the purposes of this study only the most basic non-linear products, called vanilla options are explained.

A vanilla option is the right but not obligation to buy (call) or sell (put) an asset at a predetermined price at a predetermined time in the future. In the basic cases if the option can be exercised during the life of the option it is called American and if only on the exercise date European. In foreign exchange options are almost always of European type.

Since the contract only gives the right to buy or sell at a predetermined price the payoff function is the following:

\[
\text{Payoff}_{\text{Call}} = \max \{S_T - K, 0\},
\]

\[
\text{Payoff}_{\text{Put}} = \max \{K - S_T, 0\},
\]

where \(S_T\) is the spot price at maturity and \(K\) is the strike price agreed upon.

Naturally, as the person who holds an option can only win or not lose in any scenario, the counterparty must be compensated for giving such a possibility.

The pricing of options is difficult. In theory, if the volatility of the underlying and the risk-free rates are constant and the spot price is log-normally distributed the price of a European option can be solved with a Black-Scholes-Merton model. The assumptions are, however, crudely violated in reality.
4.4 Debate on forwards and options

There is an ongoing debate on whether companies should use linear or non-linear (or more simply forwards or options) to hedge their exchange rate risk as discussed in the introductory chapter. There are no definite answers but this chapter examines some of the argumentation.

Firstly, it should be noted that given correct and fair pricing the two strategies should always lead to the same effective exchange rate in the long run. Neither is inherently better than the other.

4.4.1 Speculation

Hull (2006) states that

The arguments in favour of hedging are so obvious that they hardly need to be stated. Most companies are in the business of manufacturing, or retailing or wholesaling, or providing a service. They have no particular skills or expertise in predicting variables such as interest rates, exchange rates, and commodity prices. It makes sense for them to hedge the risks associated with these variables as they arise. The companies can then focus on their main activities - for which presumably they have particular skills and expertise.

If it seems so clear that companies should not speculate on asset prices as they have no comparative advantage in doing so why should they then speculate using options? Even though an option caps the downside risk it still leaves the company with a non-linear position in the underlying asset. Without a comparative advantage in speculating the company can never expect to win with options.⁵

Figure 2 reveals the argument of speculating with options. Assume the red line shows the profit and loss from the underlying asset. When the asset price is low, the company makes a profit. This would occur for example when the asset is used as raw material in manufacturing or when the company sales are denoted in a foreign currency. The company then hedges against the risk by buying a call option on the upside of the underlying. This way the profit and loss risk of the company is limited to the green line. But anyone can see that the resulting line is not flat. In fact, it is the P/L line of a long naked put option and naked options can by definition never be other than speculative.

⁵ Some companies, especially those involved in commodities extraction, production, refinement or other may have a comparative advantage in speculation. In fact, it is partly why some major investment banks have given up on market making in certain commodities.
4.4.2 Unsophisticated superiors

A weak but very common argument for not hedging at all or hedging with options is that treasurers who implement hedging can have a hard time convincing the management or shareholders of the company that a loss made with a forward contract was actually not a loss but rather a netting amount used to offset a favourable move in the underlying asset.

As this argument has no theoretical foundations it can at most be considered as incompetence - be it on the side of the treasurer who tries to explain the simple maths or the manager who doesn't understand the simple maths.

A hedge - as any decision - should never be judged based on the realization, but rather when the decision is made. Every lottery winner will say that buying the lottery was a good decision and every loser will say the opposite, but only a rational person can say something of the desirability of a lottery by examining the probabilities and perhaps the utility functions of the individuals contemplating it beforehand.
4.4.3 Cash flows

On paper options look much like forwards. You simply buy the other half of the forward contract with a premium. But the reality in terms of cash flows can look very different.

The cash flows from an option are deterministic on the downside and stochastic on the upside. This means that the company knows exactly how large negative cash flows it will have with an option. The same is not true for a forward contract, because it obligates the company to pay for the difference between spot and forward if an unfavourable asset price is realized. The contract dictates exactly when the cash flow occurs, but that date might not end up having anything to do with the realization of the cash flows in the underlying. Companies with a tight cash balance might be devastated by the contractual cash flows of forward contracts if they do not meet the cash flows of the underlying.

In the extreme, if for some reason the anticipated cash flows in the underlying do not materialize, the company ends up with a naked position with possibly limitless loss potential. Consider for example a financial crisis: The company has agreed to sell products for a foreign customer and hedges the anticipated cash flows with a forward contract. It may well happen that the crisis causes the customer company to go bankrupt and render it incapable to pay for the bought products. At the same time the crisis can alter the exchange rates strongly in the favourable direction for the products sold. But at the same time the exchange rates move against the forward, for which the company no longer has an underlying. To make things worse, the counterparty in the contract is almost never the customer company but a bank instead. So the bankruptcy of the customer company has no effect on the forward contract. The company is therefore long naked in a forward contract that will cost dearly at expiry if the exchange rate is below the set forward.

A similar situation can arise in a bidding war, a situation where companies compete on a project and where the winner takes all: If a company taking part in the bidding war were to hedge its expected exposure with a linear forward contract it would end up with a naked position in the underlying if it didn’t win the project. With an option the company would only lose the premium paid (and the project of course).
4.4.4 **Competition**

Sometimes competition dictates how hedging should be conducted. If a company functions in a competitive market where pricing is set by the majority of the companies it can be suboptimal to hedge with a forward when others use options.

Consider a situation where other competitors use options and one uses forwards. The company who hedges with forwards has no variation in exchange rates and therefore no (exchange rate caused) variation in the pricing of its products. If the exchange rates then turn favourable for the companies who use options they can lower the prices of their products and as a majority drop the market prices. But for the company using forwards this new price level is too low and may force it out of competition.

Then again, the company who uses forwards doesn't pay the premium of the option and can turn a larger profit those years when exchange rates are unfavourable for the ones using options. If the company hedging with forwards is able to use this to its benefit it alters the situation. Nevertheless, it must be careful with events where it might be outpriced.
5 PREVIOUS RESEARCH RELATED TO HEDGING EXCHANGE RATE RISK

The benefits and reasons for hedging currency risk are open to debate. There seems to be a consensus that hedging is in fact beneficial - the sources of the benefits on the other hand are not agreed by all scholars.

This chapter is structured as follows: It starts with the - perhaps naive - assumption that in perfect markets company decisions do not matter as long as investors can replicate them. Moving further in the chapter assumptions are relaxed and topics from internal asymmetries to topics as advanced as competition and behavioural finance are discussed.

5.1 Modigliani Miller theorem of investor replication

It is natural to start the exposition into the effects of foreign exchange rate risk and the need to hedge against the risk with Modigliani and Miller (1958) (MM, hereafter). According to the MM theory the value of a firm is independent of its capital structure if capital markets function perfectly. The theory states that an investor is always able to replicate the desired leverage of the company and thus replicate any risk level he wishes for the company.

Although not the covered in their original paper the MM theory applies to hedging as well: if investors themselves are able to hedge their currency exposure then companies serve no favour for them by hedging internal currency risk. Like the original model from Modigliani and Miller, this hypothesis rests on quite strong assumptions. Firstly, currency markets are not perfect and individual investors face higher relative transaction costs than companies do.\(^6\)

Secondly, it assumes that currency risk affects the company and the individual investor in the same way. The second assumption is perhaps the more important and includes a wide array of theories ranging from taxation to behavioural finance covered below.

\(^6\) Assuming the individual investor is a smaller player in the markets than the company it invests in. The sheer size of hedge nominal is not enough to determine who pays the highest transaction costs as banks often give discounts on secondary transactions (FX in this case) if the primary transactions (e.g. financing) bring them enough income.
5.2 Internal asymmetries

The article from Froot, Scharfstein & Stein (1993) (FSS, hereafter) studies optimal risk management strategies for corporations of different characteristics. The article's argumentation builds on the assumption that variability in cash flows - be it caused by foreign exchange risk or other - will show up as variability in the amount invested. Since companies often face a concave investment profitability function, they are unwilling to have variability in the investment amount and will likely try to reduce the variability by raising external financing to balance the differences. Concavity is depicted in Figure 5 on left hand side.

If the supply of external financing is not perfectly elastic and the company faces a convex external financing function it will try to avoid variation in it as well. Convexity is depicted in Figure 5 on right hand side. The end result for the company is a concave profitability function where part of the concavity arises from the investment profitability function and part from the external financing function. If the company is able to reduce this variation by hedging it will increase the value of the firm despite the Modigliani Miller type assumption that hedging could be externalized to investors.

The model starts with the net present value function for investment expenditures

\[ F(I) = f(I) - I, \]

where \( I \) is the amount invested, and \( F(I) \) the expected level of output. The function \( f \) is assumed to be everywhere increasing (\( f' > 0 \)) and concave (\( f'' < 0 \)) as mentioned earlier. The investment is financed either with internal sources (cash flow), \( w \), or with external sources (debt), \( e \):

\[ I = w + e \]

\[ \text{Costs are negative profits and negative convexity is concavity} \]
The company then tries to maximize its net expected profits

\[ P(w) = \max, F(I) - C(e), \]

where \( C(e) \) is the convex function for external financing resulting in the following expression:

\[ P_{ww} = f_{II} \left( \frac{dI^*}{dw} \right)^2 - C_{ee} \left( \frac{dI^*}{dw} - 1 \right)^2 \]

The function states that the concavity in the company profitability arises both from the concavity in the investment profitability function and the (negative) convexity in the external financing. If the expression is globally negative, hedging raises average profits.

The result of concavity is paramount for there to be internal reasons for hedging. Much of this paper is based on the finding. Even though FSS model is applicable in a long-term setting, it fails to take accumulation into account. It merely states that cash flow variation will entail a cost. But in reality external impulses may cause more serious trouble for the company if the problems accumulate over time.

5.3 Tax convexity

Smith & Stulz (1985) analyze the effects of taxation on company performance when facing an external source of risk. If a company faces a convex tax rate it is beneficial for the company to hedge away any sources of risk that can cause cash flows to vary. The convexity in the tax rate can arise from progression or inability to perfectly carry tax losses forwards and backwards.

To further study the effect of taxation it is important to take into account the actual ability to utilize tax loss carry forwards and backwards. Taxation depends on the company's local jurisdiction and varies from a country to another. In general, tax losses can be carried forward far in the future and in some cases backwards a year or two. Table 2 gives an overview of regulations in different jurisdictions.
<table>
<thead>
<tr>
<th>Country</th>
<th>Loss Carry Forwards</th>
<th>Loss Carry Backwards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>Indefinitely, subject to continuity of ownership</td>
<td>No carry back allowed, years 2012-2013 an exception</td>
</tr>
<tr>
<td>Canada</td>
<td><strong>20 years</strong>, if carrying on same business with a view to profit</td>
<td>Usually <strong>three years</strong>, subject to limitations</td>
</tr>
<tr>
<td>Finland</td>
<td><strong>10 years</strong>, can be limited if change in ownership</td>
<td>No carry back allowed</td>
</tr>
<tr>
<td>Germany</td>
<td>Indefinitely, up to 1MEUR, 60% after 1MEUR</td>
<td><strong>One year</strong>, limited to 1MEUR</td>
</tr>
<tr>
<td>Japan</td>
<td><strong>9 years</strong> for blue form tax return SMEs, 80% for non SMEs</td>
<td><strong>One year</strong>, in limited circumstances (incl. SMEs)</td>
</tr>
<tr>
<td>Spain</td>
<td>Indefinitely, up to 70% from year 2016 onwards</td>
<td>No carry back allowed</td>
</tr>
<tr>
<td>Switzerland</td>
<td><strong>7 years</strong>, likely to be changed to indefinite with 80% limitation</td>
<td>No carry back allowed</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>Indefinitely, subject to continuity of ownership</td>
<td><strong>One year</strong></td>
</tr>
<tr>
<td>United States</td>
<td>In general <strong>20 years</strong></td>
<td>In general <strong>two years</strong></td>
</tr>
</tbody>
</table>

Table 2  **Tax loss carry backwards and forwards in different tax jurisdictions.** Sources: Australian Taxation Office, Canada Revenue Office, Finnish Tax Administration, PWC, KPMG, Deloitte, Altschuler, Auerbach, Cooper & Knittel (2009)

As can be seen from the table companies are able to carry their losses far enough in the future for most purposes. If a company runs a loss for more than 7 years it is likely facing more serious problems than tax convexity.

But even if a company were fully able to carry forward its losses it doesn’t get compensated for its opportunity costs. In other words, the present value of the future tax reductions is less than an income tax of equal size. The subject of alternative cost comes into play when a company needs to cut back on investments or raise external financing due simply to the inability to perfectly even out tax variation.
5.4 Concavity in investments

There are internal factors in companies which cause investment profitability to become concave. This rather technical topic can be introduced with the words from Lessard (1990):

"... the most compelling arguments for hedging lie in ensuring the firm's ability to meet two critical sets of cash flow commitments

1) the exercise prices of their operating options reflected in their growth opportunities (for example, the R&D or promotion budgets) and

2) their dividends - -

The growth options argument hinges on the observation that in the case of a funding shortfall relative to investment opportunities, raising external capital will be costly."

When investments are discussed in a real options setting it becomes very concrete why missing out on investments is so harmful to companies. An option costs money to buy. When the option has been bought all that needs to be done is to wait and finally exercise the option if it lands "in the money". If an investor bought an option to buy (i.e. call) a stock index, but were unable to exercise it when the index exceeds the exercise price not only would the investor miss out on the opportunity to make a lot of money, he would also lose whatever he paid for the option in the first place.

Now, if we translate this analogy to the real options case we can see that a company also "pays money" for an option and exercises it if the option is "in the money". Companies rarely buy real options with actual money but rather facilitate opportunities for growth or cut-back opportunities.

An example could be building a factory with extra room for future expansion. This extra room costs a little more (and represents the cost for the option) but enables the company to cheaply expand to different production opportunities (representing the exercise of the option). Later, the company could have made calculations on the production expansion and noticed that it is profitable because it doesn't require building a factory of its own (meaning that the real option is "in the money"). Now, as in the financial options setting, if the company doesn't have the necessary funds to do the production expansion, it will lose both the growth opportunity and the money invested in the larger factory.
At the same time, companies can only "buy" a limited number of real options. It would not make sense for them to aim for an infinite amount of investment opportunities because they all entail a cost; building an infinitely large warehouse simply makes no sense. This renders companies unable to utilize very large quantities of excess profits as there are only a finite number of exercisable real options.

If companies lose money when they are unable to exercise their investments and have a finite amount of investment opportunities the investment profitability function becomes concave and any variation in the investment amount causes the company to run inefficiently or directly lose money.

The concavity in investment profitability function can be explained as follows: Companies have a finite amount of profitable investments. In fact, companies tend to rank investments by their expected profitability and thus the expected profitability of the N+1th investment is always lower than that of the Nth. When more money is spent on investments there is a point when the last investment will have a lower expected return than the minimum acceptable rate of return, known as the hurdle rate, and will destroy value. In order to prevent value destruction the company is likely to pay the excess cash to shareholders after the hurdle rate is met. Sharing the excess cash with shareholders will limit growth to the level of investments made thus far. The hurdle rate and project selection are discussed in Berk & DeMarzo (2007).

The form of the investment profitability function can also be explained with the law of diminishing marginal product discussed in Varian (2010). It states that increasing one factor of production while another is fixed causes the productivity to increase at a decreasing rate. The same applies for example to the scale of an investment. While increasing the size of a factory investment might lead to higher expected returns, it will do so at a decreasing rate when at least one other factor remains fixed.
5.5 Convexity in external financing

Raising external finance always entails a higher cost than reducing it by an equal amount saves for the company. Much of it is caused by information asymmetries between investors and the management but even transaction costs can play an important role.

It is natural to discuss the costs of external finance using the pecking order framework put forth by Stewart Myers (1984). The pecking order hypothesis - rudely taken out of context - states that

1. Firms prefer internal finance.
2. They adapt their target dividend payout ratios to their investment opportunities...
3. ... the firm first draws down its cash balance or marketable securities portfolio.
4. If external finance is required, firms issue the safest security first. That is, they start with debt, then possibly hybrid securities such as convertible bonds, then perhaps equity as a last resort.

The preferred order of financing stems at least from three sources: Transaction, or underwriting costs, signalling costs and effects on the company's leverage ratio. The sources of the pecking order are discussed in sections 5.5.1 - 5.5.3 below.

5.5.1 Transaction costs

Whenever a company funds itself externally it faces transaction costs. These costs include the gross spread which consists of management fees, underwriting fees and selling concession and other direct expenses such as registration fees, legal and auditing costs.

Lee, Lochhead, Ritter & Zhao (1996) investigate these costs in their article The Costs of Raising Capital. Their findings regarding transaction costs can be summarized in Figure 3 which shows the transaction cost as a percentage of issue size on the y-axis, size of the issue in millions of dollars on x-axis and type of issue on z-axis.
Figure 3. Total Direct Costs as a Percentage of Gross Proceeds for Equity IPOs and SEOs, Straight and Convertible Bonds. Source: Lee, Lockhead, Ritter, Zhao 1996

The figure suggests two things: considering only transaction costs it is preferable to issue debt when using external funding and it is preferable to raise larger quantities at once rather than issuing several small series as it exhibits economies of scale. The transaction cost evidence suggests that continuous adjustment of external financing is suboptimal.

5.5.2 Signalling

When companies issue equity it might be taken as an indication that the management considers the company to be overvalued and can cause a drop in the market price of the company (Mikkelson & Partch 1986). This can be considered generally as an Akerlof’s (1970) lemons problem or more specifically as a Myers & Majluf (1984) conflict of interests between new and old investors. The conflict arises from information asymmetry between management and the investors, both old and new.
In short, if a company has financial slack in the form of cash or marketable securities and still issues equity it is a clear signal to investors that the stock is overpriced. Signals of this sort will cause the stock price to fall with certainty. If on the other hand the company doesn't have slack and doesn't have access to risk free debt securities the situation is a bit more complicated: depending on the investment payoff distributions the company might issue equity on new investors’ expense for an unprofitable investment, issue equity for a profitable investment benefiting all stakeholders or simply refrain from issuing and investing.

Given that the outsiders are unaware of the distributions of the investment payoff and there exists scenarios where new investors get deceived by management there must be a discount factor related to the issuance - relative to the situation with perfect information. Companies are therefore unwilling to issue equity as the issuance is likely to cause a drop in the market value of the company. Issuing equity to cover for losses made with exchange rates would therefore be only a last resort.

5.5.3 Leverage ratio

If the company finances itself externally it is likely to affect its leverage ratio. Assuming the company is running at an efficient debt ratio, changing the ratio will be suboptimal. Higher levels of debt will increase the probability of default and lower levels decrease the discounted value of the interest rate tax shield. Thus financing investments with an equity issue reduce company value because the interest rate tax shield is affected and financing them with debt will increase the probability of default and therefore decrease company value.

While purely theoretically bankruptcy is a non-event in the sense that only ownership changes hands, in reality it does incur a great deal of both direct and indirect costs. Even though the direct costs of a bankruptcy, such as litigation costs, are more easily estimated they often represent only a fraction of the total costs. Indirect costs contain anything from lost customers and employees to fire sales of assets. Raising debt the company becomes more levered and increases the probability of default.

Other factors which affect the optimal debt ratio include but are not restricted to managerial problems such as empire building, suboptimal investment and excessive perks, agency costs stemming from the misaligned incentives of debt and equity holders and direct financial issues such as the amount of interest paid.
In short, managerial problems are reduced when the leverage ratio is increased, agency costs are reduced when leverage is reduced and interest costs are - of course - higher the higher leverage is. The factors will not be discussed more thoroughly as they are outside the scope of this paper, but an interested reader can get acquainted with the works of Jensen & Meckling (1976) for over-investment or asset substitution problem, Myers (1977) for under-investment or debt overhang problem, Jensen (1986) for wasteful investment and empire building and Harris & Raviv (1990) for disciplinary effect of debt.

The connection between debt (ratio) and value of the company is depicted in Figure 4, where increasing the amount of debt gradually increases the value of the firm until a point where the negative effects of debt start to dominate. The figure serves to show the concave behaviour of debt ratio and how the company value is decreased whenever the company is forced outside the optimal level of debt, be it towards lower or higher levels of debt.

![Figure 4](image_url)  
**Figure 4**  
**Optimal leverage ratio.** Value of company increases due to interest rate tax shield and managerial incentives until a point where financial distress and agency costs start to dominate.
5.6 Management risk aversion

The wealth and future cash flows of company management are often more tied to the performance of the company than its owners', because owners tend to be better diversified from the idiosyncratic risk of the individual firm (Jin 2002). The fact that managers have to take a disproportionate amount of individual firm risk may cause them to become risk averse with respect to the company. Therefore it is in their best interest to hedge away any external sources of risk - including exchange rate risk (Stulz 1984).

However, the reasoning above only holds if the manager is competent and confident of his managerial skills. An incompetent manager would actually have incentives to increase the number of sources of variation in the company's cash flows in order to create a fog screen to shade out the company's actual performance. If a manager has hedged away all external sources of risk in the company and the performance still is inadequate the manager will have a harder time to convince shareholders that the poor performance was outside the hands of the manager. If on the other hand the manager can blame unusually high material costs or unfavourable exchange rates for the company performance he might be able to hide away his own incompetence. This type of competence signalling was brought up by Breeden & Viswanathan (1990).

5.7 Investor considerations

Although everything in this chapter and the paper in general is related to investor considerations this subchapter covers the most visible parts of the company to the investors: performance in financial statements and dividends.

5.7.1 Earnings variability and asymmetric reactions

A well-diversified investor should only be concerned about the return and the systematic risk of his investments - not the company specific idiosyncratic risk. Therefore variation in the earnings of the company should have no effect on the desirability of the company stock - assuming the variation is not reflected in the stock price. In reality, however, investors do follow the financial statements as they convey information of the future performance of the company and thus indirectly affect the price as well. Therefore, minimizing variation in the financial statements is desirable for the company.
Furthermore, according to the prospect theory, loss aversion should cause investors to react more strongly to negative earnings surprises than to positive ones. In the words of Fox (1997):

"In January, for the 41st time in 42 quarters since it went public, Microsoft reported earnings that meet or beat Wall Street estimates....This is what chief executives and chief financial officers dream of: quarter after blessed quarter of not disappointing Wall Street. Sure, they dream about other things...But the simplest, most visible, most merciless measure of corporate success in the 1990s has become this one: Did you make your earnings last quarter?"

Woodruff & Senchack (1988) find that firms with unfavourable or very unfavourable earnings surprises show a larger intraday reaction than favourable or very favourable surprises. This asymmetry in earnings reactions is, however, largely debated.

### 5.7.2 Dividend smoothing

The dividend policy of the company comes back again to signalling. Companies often smoothen their dividends and are very reluctant to cut them because managers believe that investors prefer stable dividends and take dividend cuts as a signal of expected future hardship (Lintner 1956). Therefore companies should minimize cash flow variation so that they are better able to forecast and meet future dividends. There is, however, limited evidence that this actually holds in practice.

### 5.8 Competitor considerations

There are competitive situations where hedging is not always directly a good thing. The topic is studied in Adam, Gasgupta & Titman (2007) (AGT, hereafter). The authors argue that there are competition equilibriums where some firms hedge and others do not even though all firms are alike before end game payoff realizations. The fraction of hedgers depends on demand elasticity, number of competitors and the convexity of production costs.

The idea is based on a real options rather than the more familiar risk reduction argument. The base setting of the model resembles that of FSS, which is covered thoroughly in section 5.2, with the main exception that firms have no access to external finance. Like in FSS, the firms are faced with an everywhere increasing and concave investment function and a stochastic external impulse that can be costlessly hedged away.
In AGT the production function of a firm depends on two factors $X_1$ and $X_2$ (raw material and labour) according to equation

$$q = \min \left[ \gamma(k)X_1, X_1^{1/2} \right],$$

where $\gamma(k)$ is the increasing and concave investment function familiar from FSS discussed in section 5.2 and $k$ is the amount of funds available for investment. The variable $k$ is deterministic for companies who hedge and stochastic for those who do not hedge. Consequently, the cost function

$$C(q, k) = \frac{c}{\gamma(k)} q + \frac{\delta}{2} q^2,$$

where $c$ and $\frac{\delta}{2}$ represent the unit costs of variables $X_1$ and $X_2$ respectively, is convex in $k$ for all $q$. Thus hedging is beneficial in the spirit of FSS.

If we assume that firms are price takers the price equals marginal cost and the profit function becomes

$$\Pi(k, P) = \frac{1}{2\delta} \max \left\{ \left( P - \frac{c}{\gamma(k)} \right), 0 \right\}^2$$

The maximum function arises from the assumption that firms only produce when the price exceeds the marginal cost of factor $X_1$. The interesting point about the profit function is that it resembles the payoff function of a bought option which according to option theory is always non-negative. Thus the profit function is convex in $P$, which again implies that for a fixed $k$ a firm benefits from volatility in $P$. For sufficiently small values of $P$ the profit function is even convex with respect to $k$. That can be shown studying the second derivative of the profit function with respect to $k$ (omitted here). The fact that a company’s profit function can at times be locally convex is an important finding. It suggests that hedging can be (locally) suboptimal.

Studying the behaviour of firms in a two-stage dynamic game where the price level is determined by the hedging decisions and realizations of the cost shock AGT are able to show that there in fact exist interior equilibriums where it is optimal for some firms to hedge and others not to hedge.

---

8 In fact $k = y$, which itself is $y = \bar{y}$ for hedgers and $y = \bar{y} + \epsilon$, $E[y] = \bar{y}$ for non-hedgers

9 Long call option payoff is $\max(S - K, 0)$
5.9 Long-term perspective in investment setting

Elroy Dimson, Paul Marsh and Mike Staunton published a book in 2002 named Triumph of the Optimists - 101 Years of Global Investment Returns. The book contains a comprehensive overview of asset returns over a period revealed in the name. The return information is annually updated in the Credit Suisse Global Investment Returns Yearbook. In addition to covering investments such as equities and bonds it also covers inflation and exchange rate variation.

The CS Global Investment Returns Yearbook from 2012 has a section dedicated to examining the benefits of hedging currency exposure in an international investment setting. The authors argue that the benefits depend on the investor's horizon so that hedging currency risk in long-term investments can be suboptimal.

According to the book all 19 currencies studied showed a less than one percent annual exchange rate change in real terms. This means that even though for example the USDGBP exchange rate went from five dollars to 1.55 against the pound from 1900 to 2012 with an annualized decrease of 1.01% in nominal terms, it actually weakened only by 0.05% annually in real terms. It suggests that currency rates exhibit long-run stability in real terms. The authors argue that because inflation indices were less accurate in the past, the true annual real exchange rate changes might be even smaller than the data implies.

While real exchange rates are relatively stable in the long run, the data indicates that short term deviations from the fundamental exchange rates can be significant and currencies are volatile for international investors.

Since short-term exchange rate variation in real terms is high and long-term variation relatively low the study suggests that hedging in an investment setting only makes sense in the short run. The situation is exacerbated when taking interest rates into account. When hedging long-term risk the interest rate risk actually increases overall risk making long-term currency hedging suboptimal in an investment setting. The results are to some extent shared by Hauser, Marcus & Yaari (1994).
5.10 Summary of previous research

There are a number of reasons why firms should hedge their foreign exchange risk even if investors were able to do the same on their own. While investor considerations and behavioural finance bring their part to the table the most compelling reasons for hedging arise from the way the company functions as a machine. Whenever the company is forced to ride along the concave investment function or the convex financing cost curve it loses money.

This paper investigates specifically how the mechanical problems manifest themselves in the long run when the company does not hedge its currency risk or does so with the use of linear or non-linear contractual hedges - something that is widely neglected in the academic research. The long-term perspective takes accumulation into account and generalizes better than a simple one-period model.
6 MATHEMATICAL EVIDENCE

The effect of internal asymmetry can be visualized mathematically with the help of concave and convex functions and a symmetric source of risk. The purpose of this chapter is to simplify and introduce the empirical study which is described in detail in section 7.

If a company has a concave investment profitability function, F, and a convex cost function for external financing, C, symmetric variation in cash flows will destroy company value in the long run.

If the investment profitability function, F, is everywhere increasing and strictly concave \( F'(w) > 0, F''(w) < 0 \) for all \( w \) and the cost function for external financing, C, is everywhere increasing and convex \( C'(d) > 0, C''(d) > 0 \) for all \( d \), the company will always lose more money when hit with a negative cash flow impulse than it gains with a positive cash flow impulse of the same magnitude. This can be easily shown with Jensen’s inequality as in Myers and Smith (1982) and Smith and Stulz (1985), but a heuristic exposition suits the purpose better.

For the sake of exposition let’s assume that \( F(w, i) = e - e^{-(w+i)} \) and \( C(w, i) = e^{(w-i)} \), and that the company runs optimally when the external impulse \( i = 0 \). The functions are shown in Figure 5 with investment concavity on the left and convexity in external financing on the right hand side. If \( i^+ > 0 \) the company can either increase its rate of investment or reduce its cost of external financing. This leads either to an increase in investment returns \( \Delta F(w, i^+) = e - e^{-(w+i^+)} - (e - e^{-(w)}) = e^{-(w)} - e^{-(w+i^+)} > 0 \) or to a reduction in the cost of external financing \( \Delta C(w, i^+) = e^{(w-i^+)} - e^{(w)} < 0 \). The company will maximize the value impact by choosing the larger of the changes: \( \Delta V(w, i^+) = \max\{\Delta F(w, i^+) ; \Delta C(w, i^+)\} \).
Figure 5  Concavity in investments and convexity in external financing

If, on the other hand, \( i^- < 0 \), the company must reduce its rate of investment or take on more external debt to maintain the investment rate thus increasing the cost of external financing. This leads either to a decrease in investment returns \( \Delta F(w, i^-) = e - e^{-(w+i^-)} - (e - e^{-(w)}) < 0 \) or to an increase in the cost of external financing \( \Delta C(w, i^-) = e^{(w-i^-)} - e^{(w)} < 0 \). The company will minimize the value impact by choosing the smaller of the changes: \( \Delta V(w, i^-) = \min\{-\Delta F(w, i^-), \Delta C(w, i^-)\} \).

But if the impulses are equally large, i.e. \(|i^+| - |i^-| = 0\) the company must lose money. This is because the changes and the value impact are always strictly larger on the negative events than on the positive ones:

\[
\Delta V(w, i^-) > \Delta V(w, i^+) \iff \\
\min\{-\Delta F(w, i^-), \Delta C(w, i^-)\} > \max\{\Delta F(w, i^+) - \Delta C(w, i^+)\} \iff \\
\min\{-\left(e - e^{-(w+i^-)} - (e - e^{-(w)})\right); \left(e^{(w-i^-)} - e^{(w)}\right)\} > \max\{\left(e - e^{-(w+i^+)} - (e - e^{-(w)})\right); \left(e^{(w+i^+)} - e^{(w)}\right)\}
\]

This can be modelled neatly using a cosine wave, which is a smooth repetitive oscillation around zero. Even though a cosine wave is perfectly symmetrical, the non-linearity in the investment and cost functions cause the theoretical company to gradually lose value as shown in Figure 6.
The simple model is of course a bad representation of reality and doesn't for example take into account risk buffers companies can use. If a company simply holds excess cash to meet variability in cash flows it will not have to cut down on investments or turn to external financing when cash flows are weaker. But because holding excess cash is also costly it is likely that companies will suffer for the non-linearity when cash flow impulses are large enough.

Also, companies rarely run with a zero average profit as the simple mathematical model assumes. The mathematical model assumes that at average exchange rates the company runs unprofitable and turns a negative profit the second exchange rates turn unfavourable. In reality, especially matured companies, run a stable positive profit during normal years and report negative earnings only when things go bad enough. The empirical study in this paper aims at being a more realistic representation of the non-linearities.
7  **EMPIRICAL PART**

The empirical study in this paper is a Monte Carlo simulation which describes the performance of a simplified pro forma company when exposed to currency risk. The simulation is best described by dividing it into two modules: The first module simulates exchange rates and represents the stochastic part of the simulation. The second module represents the company logic and is perfectly deterministic.

7.1  **First module: Simulating the exchange rates**

Despite the accuracy and easy access to exchange rate data there actually aren’t that many time series of exchange rates since there only exists one time series for each currency pair. And since each exchange rate can be replicated with two other exchange rates in the triangle 1/3 of them are redundant for analysis purposes. Due to the small sample problems any studies conducted with real data are highly dependent on the time window and exchange rates chosen. Comparing for example options to forwards in a trending exchange rate is very questionable.

To be able to study the effects of exchange rate behaviour it is wise to turn to simulation. Therefore the data used in this study are completely computer generated. The simulation is, however, inspired by real data as each simulated time step uses the interest rate differentials, volatilities and correlations that were present that particular time step.

For tractability of results and for the widespread understanding of its behaviour, the exchange rates will be simulated using *correlated Geometric Brownian Motions*. Simulation in general will be introduced in section 7.1.1. Since a simulation requires a (quasi) random factor the randomness is presented with a Sobol sequence covered in section 7.1.4. Correlation will be measured with implied correlations (section 7.1.6) and induced with the Cholesky decomposition (section 7.1.5).
7.1.1 Monte Carlo simulation

Before delving into the technicalities of a simulation it is important to first discuss Monte Carlo in general.

In probability theory the goal is often to measure relative length, area or volume. A bus arriving within 10 minutes given that the bus route takes 30 minutes is an example of relative length. Another classical problem is the probability of hitting a bull’s eye in darts given that the player hits the dartboard. This probability is the relative area of the bull’s eye compared to the total area of the dartboard. A confident player with only one dart would say: "Given that the relative area of the bull’s eye is \( \frac{1}{100} \text{cm}^2 \) my chances of hitting it are 1 %".

Monte Carlo uses this idea in reverse by calculating the length, area or volume of a set by interpreting the volume as a probability. In the darts example this would mean that we don’t know what the area of the bull’s eye is, but we try to estimate it by randomly throwing darts at the dartboard and calculating the probability of hitting the bull’s eye. A second player with no shortage of darts would say: "Given that the area of the dartboard is 100 cm\(^2\) and I have only hit the bull’s eye 100 times with 10 000 darts the area of the bull’s eye must be 1 cm\(^2\)." As can be seen from the sheer number of the darts needed, Monte Carlo is strongly tied to the law of large numbers. In essence, it means that by having enough darts the estimate will converge asymptotically to the true value.

In reality it would be inefficient to estimate the area of the bull’s eye by throwing darts at it (even imaginary ones), but there are situations where Monte Carlo is the fastest or perhaps the only way of solving the problem.

7.1.2 Monte Carlo for solving integrals

Monte Carlo can be used for solving integrals as well. Consider estimating the integral of a function \( f \) over a unit interval.

\[
X = \int_0^1 f(x)dx
\]
The problem could be solved exactly by solving the anti-derivative of $f$ and calculating the difference at points 1 and 0:

$$X = F(1) - F(0)$$

It can also be estimated by representing the integral as an expectation $E[f(U)]$ with $U$ uniformly distributed between 0 and 1. If we can draw $N$ independent and uniform random points from $[0, 1]$ we can evaluate the function at those $N$ points and average the results producing the Monte Carlo estimate:

$$\hat{X}_{MC} = \frac{1}{N} \sum_{i=1}^{N} f(U)$$

If $f$ is indeed integrable over $[0, 1]$ then by the strong law of large numbers,

$$\hat{X}_{MC} \to X \text{ with probability 1 as } N \to \infty.$$  

If we set

$$\sigma_f^2 = \int_0^1 (f(x) - X)^2 \, dx,$$

then the error $\hat{X}_{MC} - X$ in the Monte Carlo estimate is approximately normally distributed with mean 0 and standard deviation $\frac{\sigma_f}{\sqrt{N}}$. The form of the standard error is a central feature of the Monte Carlo method. The convergence rate $\frac{\sigma_f}{\sqrt{N}}$ holds for all integrals of dimension $d$ (Glasserman 2003).

### 7.1.3 Geometric Brownian Motion

In addition to solving integrals the Monte Carlo method can be applied to all kinds of problems where the purpose is to examine a vast number of scenarios and draw conclusions relying on the law of large numbers. The main difficulty is in determining how the scenarios are realized.

Derivatives pricing requires a process that represents the behaviour of the underlying asset in order to estimate the value of the derivative. Since pricing derivatives has come far with modelling financial instruments it is natural to borrow the models developed in that area to mimic the behaviour of currencies in this experiment.
While there are a multitude of different analytical and an endless array of numerical processes to choose from this experiment relies on the best known and most widely used stochastic process, the Geometric Brownian Motion.

A stochastic process, $S_t$, follows a Geometric Brownian Motion if it satisfies the following stochastic differential equation (SDE):

$$dS_t = \mu S_t dt + \sigma S_t dW_t$$

Where $W_t$ is a Wiener process and $\mu$ (drift) and $\sigma$ (volatility) are constants. The SDE basically says that the (infinitesimal) change in the asset is the sum of a deterministic drift, usually the risk-free rate, and a random variable which is scaled with the asset's volatility. The solution of the SDE is

$$S(T) = S(0) \exp\left(\left[\mu - \frac{1}{2}\sigma^2\right]T + \sigma W(T)\right),$$

where $S(T)$ is the terminal asset price and $S(0)$ the price in the beginning. The random variable $W(T)$ is normally distributed with mean 0 and variance $T$. Therefore we can write the terminal asset price as

$$S(T) = S(0) \exp\left(\left[\mu - \frac{1}{2}\sigma^2\right]T + \sigma \sqrt{T} Z\right)$$

if $Z$ is a standard normal random variable. In an exchange rate setting the drift $\mu$ would simply be replaced with $(r_d - r_f)$, where $r_d$ and $r_f$ denote the domestic and foreign risk free rates, respectively.

Now the terminal value of an exchange rate can be represented with known constants $(\mu, \sigma, S(0), T)$ and a standard normal variable $Z$. The different paths for the exchange rate can thus be simulated by drawing uniformly distributed and independent variables in the interval $(0,1)^{10}$, turning them into standard normal using the inverse standard normal density function and calculating the terminal value for each $Z$.

---

10 Open interval $(0,1)$ because the inverse standard normal function gets values -infinity and infinity with the values at the endpoints of the closed range
7.1.4 **Low-discrepancy sequences**

Drawing independent and uniform random variables can be quite time consuming if the problem at hand is very complex and requires a large number of random values to converge. In this case the problem is a multi-asset, path-dependent, non-linear simulation which requires up to $3 \times 60 \times N$ random values, $3$ denoting the maximum number of assets, $60$ the number of periods and $N$ the number of different scenarios for each asset in each time step. Using $N=10,000$ randomly generated values for each scenario would require a total of 1.8 million random draws and would yield highly disappointing convergence according to author's own calculations.

But since simulating the paths of exchange rates only requires spanning all different scenarios in a specific range of values there is no need for a truly random process. Spanning the different scenarios using a low-discrepancy sequence instead greatly reduces the simulation time compared to a true random process while still converging to the same results. A Sobol’ sequence used in this study is an example of low-discrepancy sequences that are widely used in numerical integrations and simulations.

Since the goal is to span the open interval $(0, 1)$, interestingly enough, no true randomness or even independence is actually required. All that is required is a numerical process which produces uniform values in a d-dimensional space.

Low-discrepancy methods are based on number theory and abstract algebra rather than probability and statistics as ordinary Monte Carlo methods. The theoretical foundations and programmatic methods they are based on are far beyond the scope of this paper but to explain the benefits of using such models some of the theory will be covered in the appendix. An interested reader can get acquainted with the works of Glasserman (2003), Niederreiter (1988) and Sobol’ (1967).

7.1.5 **Inducing correlation into the simulation**

After the creation of d-dimensional Sobol’ sequences it is necessary to induce correlation into the simulation. In order to maintain the desired drift and volatility of the exchange rates the correlation should be induced already before the inverse normal Sobol’ sequences are introduced to the Geometric Brownian Motion.

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Note: The discussion on whether random processes - especially those generated by computers - can ever be truly random is endless and will not be touched in this context.
To induce correlation into randomly generated (uncorrelated) time series the desired correlation matrix must be decomposed to a Cholesky matrix discovered by André-Louis Cholesky. The Cholesky decomposed matrix is used to transform the uncorrelated time series to exhibit the desired correlation characteristics by premultiplying the time series $Z$ with the transpose of the Cholesky decomposition matrix, $C^T$.

$$Z_{corr} = C^T \cdot Z_{uncorr}$$

The Cholesky decomposition matrix is covered in more detail in the appendix.

### 7.1.6 Implied correlation

To estimate the correlation between two exchange rates two principally different methods can be implemented. The first one is the traditional correlation measure familiar from statistics and the other, implied correlation, is derived from option implied volatilities and the triangular relationship between three connected exchange rates. The derivation of implied correlation is left in the appendix for an interested reader. Here follows only an argumentation for the use of implied correlations.

The empirical study requires an estimate of volatility to price options. It is natural to use the historical implied volatilities as those have actually been used by market participants. Alternatively, the volatility could have been estimated using statistical methods and the options could have been priced using the statistical estimate. It is, however, difficult to argument why statistical volatility - which is subject to the choices of the author - had been used in the simulation instead of something that actually occurred in the history.

While the use of option implied volatilities might seem obvious and the argumentation in favour of it unnecessary, from the choice of volatility measure follows which measure of variation must be used as a parameter when simulating the paths in order not to induce bias. This means that if options are priced with implied volatilities the variation in the simulation must have implied volatilities as parameters as well.
If implied volatilities serve as variation parameters in the simulation the correlation parameters must be derived from implied volatilities for them to be consistent. Therefore the choice of parameters in option pricing determines which correlation measure must be used when simulating the paths.
7.2 Second Module: Introducing Santeri Inc.

While the purpose of generating correlated Geometric Brownian Motions is to merely simulate the exchange rates in a realistic and generally recognized method, the purpose of the company logic is to reveal the effect of stochastic exchange rates in a company in a way not presented before.

The company logic builds on two main principles: On the one hand there are simplified pro forma type accounting and legal rules and on the other there are managerial decisions (reaction functions) which aim at maximizing the shareholder value.

The company used in the simulations is built with an EMU area company in mind. Because it would have been impossible to calculate an "average" company whose financial ratios, currency exposures and performance are averages of some subsample of EMU companies a widely-known multinational corporation was used as inspiration instead. The seemingly too accurate choices of income statement and balance sheet values simply follow the 2014 financial statements of the chosen company. The currency exposures on the other hand represent the largest import and export currencies for the EMU area.

7.2.1 Income statement

The company has EUR 100,000 worth sales in the beginning. Of those EUR 100,000 some proportion comes from foreign sales. The foreign sales are fixed in the sense that the company sells the same amount of products regardless of the exchange rates. Imagine for example that the company sells 100,000 pencils which have a price 1€ in the home markets. Of those 100,000 pencils some proportions are sold in foreign currencies. In one scenario the company has a 48% exposure to USD and therefore sells 48,000 pencils in that market that year. The EUR valued total sales can however differ from the theoretical EUR 100,000 because the company is exposed to exchange rate risk.

Similarly, the company has a fixed theoretical cost of goods sold (CoGS). If the company has no exchange rate risk on imports then it will always have the same proportional cost structure. The cost of goods sold remains fixed as 71.3% of the theoretical EUR valued sales (before taking exchange rates into account on either side) and is EUR 71,300 in time 0.
While not perfectly accurate on accounting terms, the EUR valued cash flows from hedging are added to the gross profit, the difference between EUR valued sales and CoGS.

In addition to having a cost of goods sold, which can be exposed to exchange rate risk in various degrees, the company also has other expenses which are again a fixed proportion of the theoretical EUR valued sales and which are not exposed to exchange rate risk. The proportion is 13.6% and remains fixed in all scenarios.

Without taking exchange rates into account the company has a 15.1% EBITDA/Sales.

For simplicity the company is assumed to have investment horizons of one period. This means that an investment cost will be directly depreciated the period investment is made. The investment rate and size of depreciation are covered in section 7.2.3, where managerial decisions are discussed.

Interest expenses are a fixed proportion of debt and are set to 4% to reflect an average risk free rate of 3.5% and an annual fee of 50 basis points. The average risk free rate is the average yield of 10 year German government bond during the simulation period.

The company is taxed at a 25% rate always when it has nonnegative earnings before taxes. The company can carry tax losses infinitely forward, but never backwards. Some tax jurisdictions already allow infinite tax loss carry forwards and since the purpose of the study is to show how non-linearities affect the company, a decision to allow the company to reduce the non-linearities as much as possible only makes the results more robust. Limiting the tax loss carry forwards in any way would only create stronger non-linearity and therefore larger differences between companies that hedge and those who don't.

7.2.2 Balance sheet

The balance sheet of the company is stripped to bare minimum without loss of generality. For example the assumption that the company sells its products and pays for the materials in cash (as opposed to credit) doesn't affect the effect of hedges nor does it make a bad financial year turn good. Making the assumption, however, simplifies the balance sheet greatly and makes interpreting results easier.
The **fixed assets** of the company are worth EUR 97,000 in the first year and are always denominated in EUR. They represent all tangible and intangible assets the company may have. In this context it doesn't make a difference whether they are production properties or a portfolio of intellectual rights.

The company has a **cash** buffer of EUR 8,000 in the beginning. This cash is only used for working capital management and not as a buffer against currency variation. Having an excess cash pool would entail an alternative cost which the shareholders would not accept in this case.

On the liabilities side the company has EUR 32k **equity** which the company does not increase or decrease. The company is assumed to be aware of the large transaction costs related to a SEO and is therefore strongly against using equity issues to cover any damages caused by foreign exchange risk.

The company has EUR 73,000 total **debt**. It is not specified whether it consists of bonds issued, a straight loan from a bank or perhaps a revolving line of credit. The company can take on more debt if it must cover significant losses entailed by unfavourable exchange rates. The company is again aware of the negative consequences of raising debt so it only does it to prevent the company from contracting in size.

If the company raises external debt it will incur a one-time transaction fee in the spirit of Lee, Lohead & Ritter (1996). The transaction cost is assumed to be 2%. This implicitly assumes that the company finances the negative impact with a straight debt which is priced as if it had a large nominal. It would be unreasonable to assume that the company raises debt every time it has a too large shock and pays high transaction fees for that. Instead it is assumed that the larger nominal debt is distributed to different periods when money is actually needed. The transaction cost of the large nominal debt is equally so distributed to the occasions when debt is raised.

### 7.2.3 Management decisions

The purpose of the management rules is to keep the company running as efficiently as possible. In the beginning the company is running at maximum efficiency. This means that additional management decisions cannot increase value through lowered agency costs, increased debt tax shield or something comparable.
Although the company operations run optimally without the input of management they must make decisions on dividends, debt, investment amounts and taxes if variation in the income stream threatens the company.

The **dividend** policy is simple. The company pays out everything that is excess for the company. The management determines the optimal investment rate which is reflected accordingly on the income statement as depreciation. If the income, taking necessary investments into account, is positive it is distributed to shareholders. The company doesn’t therefore aim at dividend smoothing.

In a similar manner, the **tax** policy is simple. The company knows it can subtract any pre-tax losses indefinitely in the forthcoming pre-tax income. The company keeps track of the cumulative pre-tax losses and uses them to reduce the tax base in the next years. Because the company has never heard of Enron - the superstar of creative accounting - it cannot use the future "tax refunds" for investments. Because of this legal obstacle the taxes are a convex function of pre-tax income.

The company faces a concave **investment** function. The source of the concavity is not specified explicitly but can be caused by any or all of the reasons listed in section 5.4. The investment function affects the growth rate the company has in the next period. While the investment function itself is not a management decision it is necessary to explain in this context.

The growth rate of the firm was after careful consideration set as

\[ G_{Actual} = G_{Base} \times \ln \left( e \times \frac{I_{Actual}}{I_{Target}} \right) \]

Where \( I_{Actual} \) denotes actual investment amount determined by the prevailing year’s success, \( I_{Target} \) denotes the optimal investment amount for that period, \( G_{Base} \) the base growth rate and \( G_{Actual} \) the rate of growth that will follow. The target investment amount is determined as a proportional amount of foreign sales not taking exchange rates into account.
The logarithmic form was chosen because it is a well-behaved concave function. The problem with simply taking the natural logarithm of actual versus target investment amount is that when the two are equal the logarithm is equal to zero. If the goal is to have 1-to-1 growth rate at optimum the function must be shifted by one. This can be done by multiplying the inner function with $e$. The form of the investment function can be seen in Figure 7.

![Investment function](image)

**Figure 7** Investment function: Solid straight line depicts investment-to-target ratio, solid concave curve depicts investment function, dashed concave curve depicts logarithmic function.

The investment function now exhibits all the desired characteristics: It is equal to one when the target investment rate is met; it decreases at an increasing rate below target and increases at a decreasing rate above target. Its derivative at target is equal to one. It also gives a natural lower boundary for the company at $\frac{1}{e}$, where the growth rate turns negative and the company starts to contract.

---

12 Or by simply adding one. Function is given in this form, because the zero point is more explicit at $\frac{1}{e}$: $\ln[e^{\frac{1}{e}}(1/e)] = 0$
An example below will make things clearer. Assume the following:

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foreign sales, $S_f$</td>
<td>100,000</td>
</tr>
<tr>
<td>Optimal investment rate, $i_{optimal}$</td>
<td>2.0%</td>
</tr>
<tr>
<td>Project investment, $I_{Actual}$</td>
<td>3,000</td>
</tr>
<tr>
<td>Base growth rate, $G_{Base}$</td>
<td>2.0%</td>
</tr>
</tbody>
</table>

$$I_{Target} = S_f \times i_{optimal} = 100,000 \times 2\% = 2,000$$

$$G_{Actual} = 2\% \times \ln \left( e \times \frac{3,000}{2,000} \right) = 2.81\%$$

The example shows that although the company invests 50% more than it would optimally; its growth rate doesn’t increase at the same rate, but 41% instead. This reflects the right hand side of the growth function. Contrarily, investing less than optimal would decrease the growth rate more than what the decrease in investment suggests.

The company makes investment decisions for the next period based on the earnings of the current year. If the company has a bad year financially the management will decide to cut the investments next year in order to protect the company. Similarly, when the company has a strong year it will try to maximize the benefit of the success and instead boost growth by investing more the forthcoming period. This is a crucial point: if the company were to have an unusually good year due to favourable exchange rates the management would be tricked into investing an excess amount into future growth - a phenomenon familiar from the real world. Investing too much the second year can turn out to be devastating for the company if it has overestimated the investment capacity.

If there were no variation in net income the company would use approximately 50% to finance investments and 50% would be distributed to the shareholders. Variation in cash flows will cause this balance to vary.
The company has a strict no shrinking policy meaning that the management will do whatever it takes to stop the company from contracting from one period to the next. The investment function gives a natural level for investment that the company must meet in order to keep the growth rate non-negative. When the $\frac{I_{\text{Actual}}}{I_{\text{Target}}}$ ratio is equal to $\frac{1}{e}$ the growth rate is exactly zero. Thus, a non-negative growth rate requires a minimum investment of $I_{\text{Actual}} = \frac{I_{\text{Target}}}{e}$. If the income available for investments is below the target (or even negative) the company will raise debt to bring the investment amount to the level of no growth.

Figure 8 shows the implementation of debt action function in Python. Given a fixed optimal investment rate ($I_{\text{Optimal}}$, Python: inv_rate), foreign sales ($S_f$, Python: foreign_sales) and realized project investment ($I_{\text{Actual}}$, Python: realized_inv) the company will see if the proportional realized investment rate is below the minimum threshold of $\frac{1}{e}$. If that is the case, the company will raise debt enough to bring the proportional realized investment exactly to the level of minimum threshold.

```python
def debt_action_function(inv_rate, foreign_sales, realized_inv):
    target = inv_rate * foreign_sales
    if (realized_inv / target) < (1 / numpy.exp(1)):
        return (target/numpy.exp(1)) - realized_inv
    else:
        return 0
```

Figure 8  Implementation of debt action function

The fact that the company doesn't allow for contraction, having variability in the growth function creates an interesting second order non-linearity. While the growth function itself is concave (first order non-linearity) the growth of the company becomes convex when negative growth is excluded. It becomes a negative-NPV growth option financed with debt.\textsuperscript{13} By merely looking at the company sales growth in certain periods it would seem that the company benefits from the internal non-linearities. This is misleading, however, as it doesn't reflect the increasing debt burden and decreasing profitability which accumulate over the years.

\textsuperscript{13} As if the thesis didn't already revolve enough around options and other non-linear payoffs
7.2.4 Different simulation scenarios

Since the simulation has been designed and coded by the author in principle everything can be altered in the simulation. However, the code has been designed so that certain assumptions can be switched on and off with simple Boolean variables.\(^\text{14}\)

7.2.4.1 Currency risk

The currency exposures have been chosen rather arbitrarily to represent the most common foreign trade counterparties for EMU area companies. According to the European Central Bank the main non-Euro trading partners for EMU area companies are the United States, Switzerland, China and the United Kingdom. Table 3 summarizes the relative exposures.

<table>
<thead>
<tr>
<th>Country</th>
<th>Exports</th>
<th>Imports</th>
<th>Currency</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>11.82 %</td>
<td>8.50 %</td>
<td>USD</td>
</tr>
<tr>
<td>China</td>
<td>5.77 %</td>
<td>12.34 %</td>
<td>&quot;USD&quot;</td>
</tr>
<tr>
<td>Switzerland</td>
<td>6.04 %</td>
<td>4.68 %</td>
<td>CHF</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>12.99 %</td>
<td>9.75 %</td>
<td>GBP</td>
</tr>
</tbody>
</table>

Table 3 EMU area exports and imports 2008-2012. Source: European Central Bank

Although the Chinese Yuan has not been perfectly fixed to US dollar, it has been quite strongly pegged. A company exposed to Chinese Yuan is still de facto exposed only to US dollar when considering the time frame of foreign sales. Companies are usually able to change price tables within a year to react to changes in exchange rates and within a year’s time frame the changes in USDCNY have mostly been negligible. Furthermore, a significant proportion of exchange with China is denoted directly in US dollar. For these reasons the imports and exports from China are interpreted as being US dollar denominated.

\(^{14}\) Boolean or binary variables only take values 1 (True) and 0 (False).
The company has therefore exposure in the three named currencies weighted relative to each other. For example it has a

\[
\frac{6.04\%}{(11.82\% + 5.77\% + 6.04\% + 12.99\%)} = 16.49\%
\]

export exposure and a 13.27% import exposure in CHF.

The simulations can be run with both import and export exposure in all different combinations ranging from no exposure in any foreign currency to exposure in both imports and exports in all listed currencies. It should be noted still that if the company has both import and export exposure in some currency then only the net amount is taken into consideration. By no means would the company hedge both sides of the currency when only the net exposure affects its operations.

The reader should bear in mind that the arbitrary choice of exchange rates and currency exposures has little effect on the results of the study as only the volatility, correlation and interest rate differentials are taken from the exchange rates and used as simulation parameters in the correlated GBM.

### 7.2.4.2 Taxation

The simulations can allow the company to use tax loss carry forwards indefinitely or not at all. Any intermediate alternatives, for example Finland’s 7 years, lie somewhere between the two extremes. It is, however, difficult to estimate the impact of different intermediate alternatives to the tax convexity from the two extremes.

### 7.2.4.3 Hedging

The company can choose from three alternative ways to deal with currency risk: It can choose not to hedge altogether, use forward contracts or use vanilla option contracts to hedge. The decision is always made by the author and stays fixed throughout the simulations. In other words, the company will never switch from hedging with options to not hedging during a simulation.
When the company uses forwards or options to hedge the contracts are priced fairly. An important fact to notice is that because the simulation follows a GBM and no cost margin is added to the forwards and options they will be *perfectly correctly priced*. An option priced with the analytical Black-Scholes-Merton formula will have exactly the same price when priced with a Monte Carlo simulation assuming a Geometric Brownian Motion. Using a "simple" GBM Monte Carlo without jumps or additional stochasticity ensures that there is no bias to any direction.

To reiterate in different words, the effective average exchange rates will be equal whether the company uses options, forwards or chooses not to hedge altogether. The differences in results therefore follow from non-linearities within the company. If there were no non-linearities, the three would yield the same results.

The company is assumed to be able to re-negotiate its customer and supplier prices in the beginning of each year. It would be unreasonable to assume that a company can never re-negotiate the pricing no matter what the level of exchange rates since prices tend to adjust according to exchange rates (or vice versa). It would also make the results of the simulation very volatile.

Figure 9 shows a small sample of simulated values for the EURUSD rate. A lot of important information is revealed in the figure. Firstly, when dealing with a Geometric Brownian Motion it is irrelevant what the spot value is at time zero. The dynamics of the simulation hold for any positive value of spot. Therefore the beginning spot value can be set to one for computational simplicity.

Secondly, as the company is able to re-negotiate its pricing with its customers and suppliers the exchange rate gets effectively brought back to unity. This is reflected in the figure in the way the simulated rates do not disperse when time goes on. Without the ability to re-negotiate the pricing, the effective exchange rates would depict a form of an opening flower with dispersion increasing towards the future.

Thirdly, the figure shows the historical dynamics of the exchange rates: The volatility in EURUSD was reduced from the early 2000s to the end of 2007 and exploded in September 2008 when Lehman Brothers filed bankruptcy. The volatility was increased again during times of sovereign debt crisis. The correlation dynamics in the exchange rates are not visible to the naked eye.
It should be noted that the assumption of re-negotiation violates any situations where the company is exposed to economic risk. For example facing domestic competition a foreign company would not be able to re-negotiate their pricing if the domestic competitor could use the new exchange rate to their advantage. Economic risk is, however, outside the scope of this analysis and will not be taken into further consideration.
7.2.4.4 *Interest rate differentials*

When comparing hedging and not hedging in a simulation there remains one source of bias which can affect the results between hedging and not hedging. If there is a non-zero drift in the exchange rates, the simulations will drive along the drift. For forwards and options that doesn’t make a difference, since they are priced taking the drift into account, and on average the accounted drift will prevail. For not hedging, however, this is not taken into consideration. Therefore, had some of the currencies a non-zero drift the results would be biased for or against hedging. In order to control for this the interest rate differentials can be forced to zero to run robustness checks on the drift thus removing the only source of possible bias.
8 DATA

Although the study is simulation based it does require inputs for the correlated GBM. The required variables are risk free deposit rates for each of the currencies, correlations between each pair and volatilities for each exchange rate. Note that spot values are not needed since all currencies can be normalized to one in the beginning. Although forward rates are also available for the exchange rates a decision was made to derive forward rates within the program as it is difficult to find interest rate data that perfectly maps the spot to the traded forward levels. Using calculated forwards instead ensures that the two hedging types used are perfectly unbiased and fair with respect to the realizations of the GBM.

Since the simulation inputs are from historical data this type of simulation could be called real data inspired. There are two clear benefits of running a real data inspired simulation compared to an author specified simulation:

Firstly, whatever parameters are put into the simulation have already occurred in the past. So the parameters can never be unrealistic. This is especially true for a path-dependent simulation because transitions from one set of parameters to another must be realistic. For instance, it is natural to assume stochastic volatility in simulations, but the speed and magnitude of a volatility regime shift is difficult to determine. When using realized volatilities as parameters the regime shifts are once again such that have naturally occurred and are possible. The clear disadvantage of this is of course that the simulation is restricted to parameter behaviour seen in the past. But then again, simulating anything that has not already occurred in the past is nothing short of guessing.

Secondly and more importantly, when the simulations follow realized data in the parameters, the simulation results can be tested against historical data completely outside the original setting. Section 9.3.1 discusses how the simulated company is forced to take on large amounts of debt due to high volatilities and correlations in the simulation at a time when credit availability was weak.

The data stretches from the first quarter of 2000 to the last quarter in 2014, a total of 15 years or 60 quarters. The chosen data period includes times of very low volatility (2004-2005), extreme volatility (2008-2009) and mediocre volatility around them.
It is interesting to see how inducing extreme volatility during Lehman crisis affects the results in the simulation. In addition to data used in the simulation, historical data on 10 year German government bonds, three month Euribor and three month Eonia Swap are needed for auxiliary analysis. All data are gathered from Bloomberg and can be considered high quality due to the massive trading volumes in all of the variables of interest.
9 EVIDENCE ON THE LONG-TERM EFFECTS OF 
EXCHANGE RATE RISK

The fact that the empirical method is conducted with a simulation controlled by the 
author enables calling for any variables in the entire simulation universe. Were it of 
interest, for example the entire evolution of interest expenses could be called for all 
iterations. The results covered here concentrate on variables that best describe the 
health of the company. In most cases only the distribution of end values are presented 
and not the paths that got the company in each end value.

The simulation program is built such that a total of 8 Boolean variables and one with 
three alternatives can be chosen. This means that the total number of (easily) accessible 
simulations is $2^8 \times 3 = 768$. The results will concentrate only on a few different 
alternatives and the rest can be considered as robustness checks. For example: the 
simulations are run with the prevailed interest rate differentials, but in order to exclude 
the possible effects of biased drift, the same simulations are also run with zero interest 
rate differentials. Robustness tests will not be reported for all cases.

9.1 Ability to generate value to shareholders

As this paper revolves around optimizing hedging in a corporate setting it is natural to 
start with the ultimate goal of all companies: the ability to generate value for 
shareholders.

The size of each dividend at time $t$ is a function of company growth until time $t$, value of 
home currency denoted sales and cost of goods sold at time $t$, cumulative tax loss carry 
forwards until time $t$, and the cost of external debt at time $t$. An individual dividend is 
therefore very volatile and tells little of the overall health of the company. The 
cumulative dividend, however, sums up the wealth creation ability for the company in 
each run.
9.1.1 Exposure to one currency

When the company has a 48% export exposure to US dollar and is allowed to carry tax losses indefinitely in the future its cumulative dividends already show subtle differences.

If the company doesn’t hedge the US dollar risk in sales its average cumulative dividend (ACD) in the last period is approximately EUR 400,180 with a standard deviation of EUR 35,708. The distribution of ACD is depicted in Figure 10.

![Cumulative Dividend: 48% USD export, no hedges, tax loss carry forwards allowed indefinitely, historical data induced drift](image)

If hedged with options the company is on average only slightly better off with an ACD of approximately EUR 401,806, but with a far superior standard deviation of EUR 18,700. The distribution is also right-skewed with ACD capped rather tightly at EUR 360,000 as shown in Figure 11.
When the company uses forwards its distribution of ACD is even tighter packed and is significantly higher than in the two previous cases (Figure 12). The average is approximately EUR \(413,622\) with a standard deviation of only EUR \(4,479\). In this case statistical significance will not be reported as it bears no proper meaning. The statistical significance of a result can simply be increased by increasing the number of iterations.

**Figure 11** Cumulative Dividend: 48% USD export, hedged with options, tax loss carry forwards allowed indefinitely, historical data induced drift

**Figure 12** Cumulative Dividend: 48% USD export, hedged with forwards, tax loss carry forwards allowed indefinitely, historical data induced drift. Graph accuracy increased for readability.
The economical significance is clear: The company is able to increase its cumulative dividend by three percent compared to not hedging. Unlike a similar increase somewhere else in the company performance, this is directly reflected in the wealth of the shareholders. The standard deviation of cumulative dividends has even greater economical significance as the standard deviation is approximately 9% of the total cumulative dividends without hedging and only 1% when hedging with forwards.

9.1.2 Exposure to three currencies

When the company is exposed to all three currencies, it means it has 100% of its sales in foreign currencies. With a larger exposure to foreign exchange the differences between three hedging alternatives start to show more clearly.

When the company doesn’t hedge the three exchange rates at all its expected cumulative dividend drops significantly. This time around the ACD is merely EUR 383,182 and the cumulative dividend has a standard deviation of EUR 56,542 - a nearly EUR 20,000 increase. This is visible in Figure 13.

Figure 13 Cumulative Dividend: 48% USD export, 35.5% GBP export and 16.5% CHF export, no hedging applied, tax loss carry forwards allowed indefinitely, historical data induced drift
By hedging the risk with options the company can again improve its average cumulative dividend compared to when not hedging at all, but still falls far short from the situation with only exposure to USD risk (Figure 14). The average is EUR 393,892 and standard deviation 25,267 - approximately half of the standard deviation when not hedging.

**Figure 14 Cumulative Dividend:** 48% USD export, 35.5% GBP export and 16.5% CHF export, option hedging applied for each currency individually, tax loss carry forwards allowed indefinitely, historical data induced drift

It should be carefully noted, however, that when the company has exposure to more than one currency and the currencies turn out to have less than perfect correlation the company has effectively overhedged itself when hedging each individual currency with 100% hedge ratio. As the simulation follows actual (implied) correlations from the estimation period, the realizations of the simulation do not follow the assumptions of the option basket and as a basket they are no longer correctly priced from the viewpoint of the company. The options are still accurately and fairly priced with respect to each individual currency but the multivariate realizations of currencies cause the total price of the options to be biased upwards.

In order to mitigate this problem the company should instead try to estimate the future correlations and determine its hedge ratios based on the assumptions or use basket options (as opposed to a basket of options) where the correlation is already priced in. Portfolio and basket hedges are not taken into consideration in this experiment, but the reader should interpret the results carefully as they are biased against the options.
When hedged with forwards the company has in practice the same ACD of \(413,004\) and a slight increase in the standard deviation to EUR \(5,689\). It is unclear why there is an increase in the standard deviation when the number of exposures is increased because in theory the company should be impervious to exchange rates, no matter how many, when hedged with forwards. The differences are not explained by a non-zero drift either, as forcing zero interest rate differentials leads to an ACD of EUR \(413,202\) and a standard deviation of \(5,591\) - almost exactly the ones with "natural" drift. The distribution is shown in Figure 15.

![Figure 15 Cumulative Dividend: 48% USD export, 35.5% GBP export and 16.5% CHF export, forward hedging applied for each currency individually, tax loss carry forwards allowed indefinitely, historical data induced drift](image)

The results indicating a higher cumulative dividend for companies who hedge their currency risk are consistent with the results of Nance, Smith & Smithson (1993). The survey of 169 Fortune 500 companies reveals that companies who hedge have a nearly 1 % point higher dividend yield than their non-hedging counterparties.

9.2 Ability to exercise real options and generate growth

While the cumulative dividends might be more interesting to the shareholders of the company, the end year sales figures are far more descriptive in this case. A large part of the argumentation revolves around the company's investments and the ability to continuously secure and exercise growth options.
If the company runs healthy, it is able to invest an optimal amount every period and doesn't suffer from riding along the concave investment profitability function. The investment profitability function - while directly determined only by the investment amount - is indirectly affected by the tax convexity and the convexity in external financing.

To keep things interesting, this time the exchange rate risk is observed on the import side and all sales are assumed to happen in the home currency. The results will be different in absolute terms compared to export risk but the implications of the results are nevertheless the same. Also, to make sure that drift has no effect on the results the interest rate differentials are forced to zero.

When the company doesn't hedge its import risk it will have variations in its income. As this income is used to determine the next year's investment amount the company will at times overinvest and at other times underinvest. The average end year sales for the non-hedging company is approximately EUR 145,626 and has a standard deviation of EUR 3,688 (Figure 16).

Figure 16 End year sales: 48% USD import, no hedging applied, tax loss carry forwards allowed indefinitely, zero drift
When compared to the non-hedging case, a company who hedges its import risk in USD has a significantly higher value for end year sales, which on average is EUR 147,734. In addition, the standard deviation is almost one third of the situation without hedging at EUR 1,332.

![Figure 17 End year sales: 48% USD import, option hedging applied, tax loss carry forwards allowed indefinitely, zero drift](image)

The company can still improve its growth during the simulation period by hedging its exchange rate risk with forwards. In that case the end period sales have very little variation and are again significantly higher than for the option hedging and non-hedging cases. This is visible in Figure 18. The average end period sales for the forward hedger is EUR 150,065 with a standard deviation of only EUR 579.
The results are again consistent with Nance, Smith & Smithson (1993) who find that companies who hedge have nearly twice the R&D/Sales ratio compared to companies who do not hedge. Higher R&D ratio presumably leads to faster growth.

### 9.3 Company actions over time and exposure to external realities

While the other results show where the imaginary company has ended up after its endeavours the results over time show how the company got there.

The purpose of making the simulations real data "inspired" rather than parameterized by the author is that the results of the simulation can be referenced with actual events in the markets.

#### 9.3.1 Demand for debt in a time of credit crunch

Assuming exposure to all three currencies on the sales side, zero interest rate differential in the simulation, ability to carry tax losses indefinitely, and no hedging the company is forced to take the most debt when credit availability in the real world is the worst.
Beginning from the Lehman bankruptcy in September 2008 the financial markets were in a deep crisis. As is usual for a financial crisis, the exchange rate volatilities and correlations shot up. Because the company in this specific simulation has 100% of its sales in foreign currency exports it will be hurt by more volatility in the exchange rates. Furthermore, if the correlations between currencies in a crisis increase, the export currencies start to behave more like one and the natural benefit of diversification disappears. In other words, the netting of currency risks reduces for the company.

Comparing the debt taking of the company and the 3M Euribor vs. 3M Eonia Swap spread, a proxy for credit crunch in the European markets, shows how the company is in greatest need of external financing when the availability of financing is at worst.

The Euribor vs. Eonia Swap spread is a proxy for credit availability in the interbank market. The Euribor (Euro Interbank Offered Rate) is an average interest rate required by banks for giving unsecured short-term loans to each other. The Eonia Swap rate, on the other hand, is a swap contract based on the Euro OverNight Index Average (Eonia). Since the swap only obligates the counterparties to swap the floating rate of interest for the fixed rate of interest it can be considered default risk free when contrasted with the Libor rate, where the principal amount exchanges hands.

Because banks partly finance their commercial lending in the interbank market any disruptions in the interbank market will be reflected on the commercial side. Therefore the widening of the Euribor vs. Eonia spread is an indicator of worsened credit supply in the non-banking industry. The topic is discussed in more detail for example in Brunnermeier (2009).

Using the Euribor vs. Eonia spread as a proxy for credit availability we can see in Figure 19 that the company has the highest demand for external financing precisely at the time of worst credit supply. In this sense even the purely internal functioning of the company is connected to its surroundings when the external source of risk is connected to the elements of the surrounding environment.
The beginning of the century reflects liquidity boom where the credit spread was too low considering the true risks involved. The credit availability was artificially boosted by US Government actions to support borrowing, failure to understand the risks involved in complex debt securities and the misconceptions of bank stability brought by assumptions of implicit government bailout policies. Due to the mispricing of credit, the Euribor vs. Eonia spread doesn't reflect the true (sustainable) credit availability in the beginning of the century and therefore does not show up as a problem for the company in demand of debt.

![Diagram](image.png)

**Figure 19 Demand for debt versus availability of credit.** Grey histogram depicts the average logarithmic increase in debt (RHS) and black solid line shows the 3M Euribor vs. 3M Eonia swap spread (LHS).

### 9.4 Summary analysis of different simulations

While the simulations can be run and examined on specific assumptions it is of great relevance to examine the behaviour of the simulation in all its easily accessible specifications. By assuming a zero interest rate differential for all simulations to avoid any source of bias a total of 384 specifications can be run with the author's model. These 384 permutations are run consecutively and gathered into a panel data set for one variable of interest at a time.
The panel consists of a dependent variable, for example average sales in each quarter, with Boolean (dummy) variables taking values 0 and 1 depending on the specification. The panel data is used to examine the effect of simulation specifications on the dependent variable.

It should be noted that the regressions are run on estimates of the simulation model. In that sense the model resembles a two-stage estimation where standard errors of the second stage should be corrected for the standard errors in the first stage. In this case, however, the standard errors of the first-stage estimation approach zero when the number of iterations increases. Therefore, there is in practice no need to make a correction for estimated standard errors. The topic of errors in the variables or errors of measurement bias is discussed in Gujarati (2003, 524-525)

Continuing on the theme of asymptotic analysis it should be noted that increasing the number of observations in a regression analysis - provided that they are consistent with each other - will lead to statistically more significant results. Therefore it could be argued that the statistical significance of any variable in this case can be increased by increasing the number of simulated observations.

9.4.1 Summarizing the ability to create value for shareholders

The first model examines the effect of exchange rate risk, hedging alternatives and tax loss carry forwards on the ability to pay dividends. The model is specified as follows

$$Div_{i,t} = \beta_0 + \sum_{j=1}^{3} \beta_j CCY_{j,i,t} + \beta_4 TLCF_{i,t} + \beta_5 Option_{i,t} + \beta_6 Forward_{i,t} + \sum_{t=2}^{T} \delta_{i,t} Time_{i,t},$$

where $Div_{i,t}$ is the average dividend in run $i$ at time $t$, $\beta_0$ is the constant, $CCY_{j,i,t}$ is an indicator variable to denote exposure to currency $j$ in run $i$ at time $t$, $TLCF$ is an indicator variable to denote the ability to utilize tax loss carry forwards, $Option$ is an indicator for using options, $Forward$ is an indicator for forward hedging and $Time$ is a time dummy. The model is an OLS regression with pooled data, where time variation is absorbed. Absorbing the time dimension has the same effect as explicitly using time dummies as described in the model specification.
Table 4  Regression results for periodical dividends

9.4.1.1  Model diagnostics

According to Wooldridge’s test (Wooldridge 2002) the model suffers from serial autocorrelation.\textsuperscript{15} The autocorrelation likely follows from the long-lasting effects of exchange rate variation which is an integral part of this paper. The standard errors are also affected by significant regime changes in volatility around the Lehman and the sovereign debt crisis. The volatility regime changes cause heteroscedasticity in the residuals. Therefore the use of heteroscedasticity and autocorrelation corrected standard errors is called for.

The model does not suffer from multicollinearity in independent variables. This is a natural finding, because the independent variables are choice indicators in different simulation permutations. From that follows that the independent variables are perfectly uncorrelated with each other. A correlation table of zeros testifies to this.

The residuals of the model are tested for non-stationarity with a Fisher-type panel data modification of augmented Dickey Fuller test proposed by Choi (2001)\textsuperscript{16}. The test clearly rejects the hypothesis of non-stationarity with all lags from 1 to 5.

\begin{table}[h]
\centering
\begin{tabular}{llll}
\hline
Variable & $\beta$ & SE $\beta$ & $P>|t|$ \\
\hline
USD Exposure & -35.1 & 33.65 & 0.30 \\
GBP Exposure & -42.2 & 34.65 & 0.22 \\
CHF Exposure & -17.3 & 34.11 & 0.61 \\
Tax Loss Carry Forward & 3.0 & 31.59 & 0.92 \\
Forward hedging & 273.9 & 24.34 & 0.00 \\
Option hedging & 41.6 & 44.53 & 0.35 \\
Constant & 6750.8 & 52.00 & 0.00 \\
\hline
\end{tabular}
\end{table}

\textit{Quarter} absorbed, robust standard errors (HACSE)

\textsuperscript{15} Stata command xtserial

\textsuperscript{16} Stata command xtunitroot fisher
9.4.1.2 Interpretation of regression results

The results of the regressions should be interpreted with care. Summing up the results with the use of regressions are not completely free of issues even though there is an inherent and to some extent forced causality in the simulation model. For example the fact that GBP risk shows up as a more important risk than USD merely reflects the fact that USD imports are larger than the GBP imports and the netting effect makes USD on average a smaller risk factor in the regression with all permutations of the simulation.

Another important issue is the effectively overhedged position in options when there are more than one currency exposure. If the company hedges all exposures fully with options its expected hedging benefit doesn’t match the premium it pays for the options in total. Only the one-currency permutations are not subject to this bias. This problem is discussed in more detail in section 9.1.2.

The panel data regression results suggest that adding a currency exposure decreases the periodical dividends for the company. It follows from the internal non-lineairities discussed in section 5.2. The result is driven by simulations where the company is not hedged and partially where it is hedged with options.

The results also suggest that a company which utilizes tax loss carry forwards (TLCF hereafter) is able to pay a higher dividend to the shareholders because it is able to reduce the convexity in taxation. The assumptions in the simulation lead to the TLCF to be in effect used for dividends instead of other performance improvements. Therefore the TLCF does not show up when studying the effects of it against sales growth. Because TLCF reduces taxation - a fruitless outflow from the point of view of the company - ability to utilize it will show up somewhere in the company performance with certainty.

It should however be noted that the effect of TLCF is dominated by hedging choices. It implies that tax convexity plays a minor role in the internal asymmetries of the company. The importance of TLCF increases with return variation around zero. So a company which has stable, positive returns will not have convexity in taxation while another company with variation in returns around zero will benefit much from TLCF.
Hedging with forwards increases the periodical dividends significantly (both statistically and economically). The dividend is approximately 4% higher when forward hedging is applied. Hedging with options increases the periodical dividend as well but to a far less extent.

The less than perfect goodness-of-fit is again an indication of the importance of studying this topic in the long-term perspective: The periodical performance cannot solely be determined on the period’s parameters. Rather, it is a combination of cumulative, most likely non-linear, effects.

9.4.2 Summarizing company health and ability to grow

The second model examines the effect of exchange rate risk, hedging alternatives and tax loss carry forwards on the ability to increase sales. The model is specified as follows:

\[ D.\, sales_{i,t} = \beta_0 + \sum_{j=1}^{3} \beta_j CCY_{j,i,t} + \beta_4 TLCF_{i,t} + \beta_5 Option_{i,t} + \beta_6 Forward_{i,t} + \sum_{t=2}^{T} \delta_{i,t} Time_{i,t}, \]

where \( D.\, sales_{i,t} \) is the average increase in sales in run \( i \) at time \( t \), and the rest of the RHS variables are from the first model. The model is again an OLS regression with pooled data, where time variation is absorbed.

| Variable               | \( \beta \) | SE \( \beta \) | \( P>|t| \) | Observations          |
|------------------------|--------------|----------------|------------|-----------------------|
| USD Exposure           | -42.5        | 9.56           | 0.00       | Cross-section N=384   |
| GBP Exposure           | -19.1        | 9.16           | 0.04       | Time dimension T=59   |
| CHF Exposure           | -4.3         | 7.94           | 0.59       |                       |
| Tax Loss Carry Forward | -0.1         | 8.12           | 0.99       | Explanatory power     |
| Forward hedging        | 79.3         | 10.06          | 0.00       | Prob > F 0.0000       |
| Option hedging         | 19.6         | 10.02          | 0.05       | Adj. R-squared 0.7393 |
| Constant               | 862.1        | 13.45          | 0.00       |

Quarter absorbed, robust standard errors (HACSE)

Table 5 Regression results for sales growth
9.4.2.1 Model diagnostics

The model explaining sales growth behaves much the same way as the dividend model. The sales could however not be studied as levels the same way dividends were because the sales growth is deterministically non-negative and the residuals would be non-stationary. Therefore the model is specified with first differenced sales as the dependent variable.

9.4.2.2 Interpretation of regression results

When studying the effect of simulation choices on the average periodical sales growth the main results are very much the same as when studying the effect on average periodical dividends: Currency exposure is again a negative factor and hedging increases the growth rate. Forward hedging has an approximate 10 % increase effect for the growth rate. Options increase growth approximately a fourth of this.

As discussed in the previous chapter tax loss carry forwards do not affect the sales growth, because benefits from TLCF are effectively used for dividends. In this case TLCF could be left outside the model with good conscience.

The explanatory power of the model is again high, but far from perfect as discussed in the previous section. Sales growth is affected by the cumulative and likely non-linear effects of foreign exchange rate risk.
9.5 Robustness checks

As was mentioned in the beginning of section 9, the combinations of different simulations are in practice endless. Therefore, all possible combinations cannot be reviewed in the results section even if they were interesting.

The findings that hedging is valuable and forward hedging is more optimal than option hedging when only the internal functioning of a company is taken into consideration are convincing for all measured variables. It applies equally well to outflows like the total interest cost paid and total taxes paid (small of course being better) and profitability measures like average gross profit, EBITDA/Sales, ROA and ROE.

9.5.1 Gross margin

In addition to studying the impact of exchange rate risk and different hedging alternatives it is important to examine the assumptions made regarding the company. The sensitivity to assumptions can be examined easily through reasoning. Starting from the income statement, the assumptions of foreign currency denominated sales and costs affect the gross profit of the company and the profitability of the company thereafter. Increasing the value of sales in relation to costs will cause the company to run a more stable positive return and the company is less subject to exchange rate variation. It will be easier for the company to avoid taking costly debt and to exercise its real options. Therefore the differences between not hedging, hedging with options and hedging with forwards will be smaller. The opposite holds when costs are increased in relation to the value of sales.

The relation turns out to be rather linear until a point where the company is no longer able to meet its investment requirement of no contraction. At that point the simulation starts to break down and companies which do not hedge quickly become very unstable. The last breaking point clearly arises when the average gross margin drops below 23% (28.7% assumed for all simulations). Below that level the company would often end up bankrupt.17

17 Bankruptcy not defined explicitly in this context. Some cases, where the company literally never makes a profit, are still quite clear.
Figure 20 carries a lot of information. It shows the average cumulative dividend for different levels of gross margin. Firstly, it shows how the sensitivity to exchange rate risk increases for the non-hedging company when the gross margin is reduced. The relation could best be described as exponential (in gross margin reduction). The same, however does not hold for the company which hedges its cash flows with forwards. In that case the relation is seemingly linear. Secondly, the figure serves to prove that the somewhat arbitrary assumptions of company parameters (gross margin, debt, etc.) are far from extreme. Compared to a gross margin of 25 %, the differences between hedging and not hedging are hardly visible at the 28.8 % level highlighted by the arrow. Still the results shown in section 9.1.1 are economically significant.

Figure 20 Sensitivity of cumulative dividend to gross margin. Dot depicts company hedging with options and cross depicts company not using hedges. Y-axis shows cumulative dividend in thousands of euro, X-axis shows gross margin of sales. Arrow points to gross margin assumed in all other than sensitivity analysis. Assumptions: Tax loss carry forwards allowed, zero drift, exposure only to USD exports.
9.5.2 Investment profitability function

The form of the investment profitability function directly affects the internal asymmetries: A more linear form leads to smaller differences between the three hedging alternatives. The form of the investment function cannot be stress-tested because it cannot be changed incrementally. Using a linear investment profitability function significantly alters the results, especially between options and forwards when the company is only exposed to one currency. The options never dominate forwards whenever the investment function is not convex.\(^\text{18}\)

9.5.3 Balance sheet

On the balance sheet sensitivities to exchange rate variation must be examined through balance sheet items which affect the income statement or the cash flows of the company. For example increasing the amount of debt increases the interest rate costs of the company and through a weaker profitability make the company more exposed to exchange rate variation. The company is surprisingly insensitive to interest rate costs: The total interest rate costs can increase by almost 200 % from EUR 2,900 to around EUR 8,500 in the beginning before causing instability. Decreasing interest rate costs mitigate the differences between the hedging alternatives but the effect is small. The results are comparable to those with varying gross margin but markedly less pronounced.

Having a larger cash balance and using the cash as a buffer against cash flow variations would have the effect discussed in section 4.1. Examining the effect of using a cash buffer would require heavy changes in the program. Altering the logic in the program would risk making comparisons to earlier versions impossible. Therefore its effect is not tested in the simulation.

The sensitivities to variables should not only be viewed in isolation. For example a company which has a smaller gross margin likely also has a smaller amount of debt and therefore smaller interest rate costs. So the true insensitivities of the company parameter assumptions are likely to be smaller in reality than what is shown in this chapter.

\(^{18}\) The last is based on assumptions. No convex profitability functions were tested.
10 CONCLUSIONS AND SUGGESTIONS FOR FURTHER STUDIES

There is an intensive and ongoing debate on whether companies should hedge their currency exposures and if they do, should they hedge with linear contracts such as forwards or should they resort to non-linear contracts such as options. This paper brings new evidence to the debate by examining the long-run consequences of internal asymmetries in a company.

When considered in isolation, a company who has concavity in the investment profitability function, convexity in external financing, convexity in taxation or a combination of the three, will suffer asymmetrically even from symmetric and mean-reverting exchange rate risk.

External impulses in the form of exchange rates will at times force the company to draw back positive-NPV investments, force it to raise costly external debt or cause it to have outright losses which are not compensated with tax refunds for the prevailing period. In other times, on the other hand, the company will be shocked positively and will have excess cash for investments, reducing debt or paying shareholders, but these improvements brought by positive shocks can never be of the same magnitude as the losses made with negative shocks.

This paper shows that a company who doesn’t hedge its exchange rate risk is fully exposed to the asymmetries that arise within the company and will perform worse than a company which uses linear hedges to remove the risk. Perhaps even more importantly, a company who hedges its exchange rate risk with options remains partly exposed to the asymmetries and can therefore never perform equally well as a company using linear forward hedges if considered in isolation.

The results are not only statistically and economically significant but also very robust to assumptions made in the simulations. If anything, the assumptions are shown to be conservative and careful.

The results, although only studied for exchange rates, can be generalized to other sources of risks as well. A company exposed to commodities or interest rate risk suffers from similar non-linearities as a company exposed to exchange rate risk.
To further study the topic it would be interesting to see the effect of different assumptions related to the form of the investment profitability function, the convexity in external financing and the most important income statement and balance sheet variables. In this paper the sensitivities of the assumptions are only tested as robustness checks, but a thorough and consistent examination might reveal valuable information of the importance of internal asymmetry for companies of different character.

To fully examine the economical importance of the paper's findings it would be important to examine how the differences between hedging methods caused by internal asymmetries relate to competition and cash flow related differences between the hedging methods. Comparing different sources of risk in a consistent manner is, however, very demanding.
11 APPENDIX

This appendix includes topics which are considered important for the thorough understanding of the thesis but which are deemed not to fit in the running text or which are of excessive technicality for the basic reader.

11.1 Sobol' sequences

This chapter shortly introduces the concept of Sobol' sequences, a type of low-discrepancy sequences widely used in simulations.

11.1.1 Van der Corput sequences

Before going into Sobol' and its further developments it is good to review an older cousin of it in one-dimensional space. A Van der Corput is a sequence whose elements form a dense set in the unit interval in a sense that for any real number in (0,1) there exists a subsequence of the Van der Corput sequence that converges to that value.

To find a Van der Corput sequence in base $b$ ($b \geq 2$) for length $N$, the first step is to convert each decimal form number $\{0, 1, ..., N-1\}$ to a base $b$ representation. Formally, every positive integer value $n$ has a unique representation as a linear combination of nonnegative powers of $b$ with coefficients in $\{0, 1, ..., b-1\}$. This can be written as:

$$n = \sum_{k=0}^{\infty} d_k(n) b^k,$$

where $d_k$ is the $k^{th}$ digit in the $b$-ary expansion of $n$.

The next step is to use the radical inverse function which maps each $n$ to a point in $[0,1)$ by "flipping" the coefficients of $n$ about the base-$b$ "decimal" point to get the fraction.

$$\psi_b(k) = \sum_{j=0}^{\infty} \frac{a_j(k)}{b^{j+1}}$$

To put it more simply, you take the sum of each $k^{th}$ digit in the $b$-ary representation with the only difference that instead of using the power $k$, you use $(-k-1)$ instead. The logic is much easier to explain through examples and the Table 6 shows a base-2 ("binary") example on the left and a base-10 ("decimal") example on the right.
A binary number can be turned into base-10 with the formula \( n = \sum_{k=0}^{\infty} d_k n k^k \) from earlier. For example, the binary 110 is \( 0 \cdot 2^0 + 1 \cdot 2^1 + 1 \cdot 2^2 = 6 \) as shown in the table. To get the Van der Corput of the same binary 110 you simply replace \( k \) with \((-k-1)\) and get \( 0 \cdot 2^{-1} + 1 \cdot 2^{-2} + 1 \cdot 2^{-3} = \frac{3}{8} \).

As can be seen by comparing the 8 first elements in a Van der Corput sequence in Table 6, the lower-base sequence is much more uniform. The uniformity of the base-2 Van der Corput sequence can be seen in again in Figure 21.

![Figure 21 Distribution of the first 7 digits in a Van der Corput sequence](image)

The base-10 sequence, on the other hand, always starts from the lower end of the interval and gradually fills it layer-by-layer with new values. In fact, the next base-10 values in the sequence after \( k=10 \) are 0.11, 0.21, 0.31 again starting from the lower end of the interval (and the lower end of the subintervals between each 10th). Therefore sequences of lower base are generally better than those of higher. Additionally, when doing computer simulations, it is always vastly faster to rely on binary calculus.
11.1.1.2 Sobol’ and Grey code

A Sobol’ sequence starts from the Van der Corput sequence but it works exclusively in base-2 and is able to build uniform sequences of dimension $d$. The points in a $d$-dimensional Sobol’ result from permutations of the Van der Corput sequence, but even a schematic explanation of a Sobol’ is outside the scope of this paper.

A further improvement to the Sobol’ is called the Grey code implementation by Antonov & Saleev (1979). The grey code simplifies the Sobol’ by replacing the binary representation $d_k(n)$ with a Grey code representation. The Grey code builds on recursion and only requires a bitwise XOR operation on the previous values in each dimension. Using XOR operations again vastly improves the computational speed of the sequence.

11.1.1.3 Speed and convergence

Glasserman compares the convergence of different Monte Carlo methods using root mean square error (RMSE) as a measure of accuracy. The comparison is done by pricing 500 options on the geometric mean of five underlying non-correlated assets. It is therefore a convergence comparison in the 5th dimension. Glasserman shows that for such specifications a Sobol’ with 65,536 elements has nearly a 100-times more accurate estimate than a traditional Monte Carlo with 50,000 elements and that the convergence rate is nearly $\frac{o}{N}$, where it is approximately $\frac{o}{\sqrt{N}}$ for a traditional MC.

In addition to providing fast convergence when considering the number of elements, drawing each element is also much faster than generating "true" random values. Creating the Sobol’ means that the computer can work mostly with binary operations while a random number generator will have to resort to time consuming operations such as calling exact processor time, position of the mouse or other quasi random elements and running numerical operations on the input. All this depends, however, on how each algorithm is implemented. For example Python’s numpy.random.rand is written in compiled C and can be far more efficient than Python implementations of Sobol’.
The speed and convergence of different methods are only of concern for the author as he is the one who has to wait for results to come up. To reiterate from earlier, using enough repetitions randomly produced variables and Sobol' sequences will converge to the same results eventually.

11.1.1.4 Scrambling the Sobol'

Because the simulations in this empirical study are path-dependent and Sobol' deterministic it is necessary to change the order of the Sobol' elements in each time step. Otherwise the Nth element of the Sobol' sequence would always be the same for each step in the simulation. Consider for example the Nth element which is equal to $1 - \varepsilon$, where $\varepsilon \to 0$. That Nth element yields an inverse standard normal value of $\infty$ as $\varepsilon \to 0$. If the Sobol' were used for each step in the path-dependent model, then each Nth element would have the same characteristics and the simulation path would always have an impulse close to $\infty$. If, on the other hand, the Sobol' sequence is scrambled, i.e. set in random order, the sequence will still have the desired low discrepancy of Sobol' but not the problem of having deterministic repetition. The scrambling in this experiment is conducted with Python's own numpy.random.scramble().

11.2 Cholesky decomposition matrix

Given a symmetric positive-definite matrix $M$, the Cholesky decomposition is an upper triangular matrix $U$ with strictly positive diagonal entries such that

$$M = U^T U,$$

where $U^T$ denotes the conjugate transpose of $U$. 
Linear algebra shows that any symmetric positive-definite matrix may be written in the form

\[ M = U^T D U, \]

where \( U \) is an upper triangular matrix and \( D \) is a diagonal matrix with positive diagonal elements. If the desired correlation matrix \( M \) is in fact symmetric positive-definite it can be written as

\[
M = U^T D U \\
= (U^T \sqrt{D})(\sqrt{D}U) \\
= (\sqrt{D}U)^T (\sqrt{D}U),
\]

where matrix \( C = (\sqrt{D}U) \) satisfies \( M = C^T C \). The matrix \( C \) is the Cholesky decomposition of \( M \).

### 11.3 Implied correlation

Implied correlation is a method of obtaining a correlation measure from implied volatilities based on the portfolio variance formula familiar from portfolio management.

#### 11.3.1.1 Triangular relationship

Unlike in most assets in the financial markets, any given exchange rate can be expressed through two other exchange rates in a triangular relationship. For example, we can express EURUSD directly as it is or through the rates EURGBP and GBPAUD. To prevent triangular arbitrage the three rates must trade within very tight boundaries.

In addition to locking the spot rates, the triangular arbitrage also dictates variance and correlation relationships within the triangle. This allows us, among other things, to calculate the implied correlation between exchange rates only using the implied volatilities in each of the currency pairs.
Denote an exchange rate by $Y_{A,B}$ where A is the foreign and B the domestic currency.\footnote{Note: The terms foreign and domestic do not in any way refer to a geological relationship. This is one of many distracting conventions in FX.} For example $Y_{A,C} = EURGBP = 0.8000$ and $Y_{C,B} = GBPUSD = 1.4285$. This forces the relationship $Y_{AB} = Y_{A,C} / Y_{B,C} = Y_{A,C} / (1 / Y_{C,B})$:

$$
EURUSD = EURGBP / GBPUSD = 0.8000 / (1/1.4285) ≈ 1.1429
$$

To make life a bit simpler the formula can be written as a subtraction as long as we calculate with logarithmic values. Denote $y_{A,B} = \ln (Y_{A,C} / Y_{B,C}) = \ln (Y_{A,C}) - \ln (Y_{B,C})$.

Since the relationship holds in exchange rate changes and the exchange rates are non-stationary, it is best to take log-level changes. Denote $\varepsilon_{A,B} = \Delta y_{A,B}$ and the triangle relationship $\varepsilon_{A,B} = \varepsilon_{A,C} - \varepsilon_{B,C}$. Now this relationship can be loosely interpreted as a portfolio consisting of two investments $\varepsilon_{A,C}$ and $\varepsilon_{B,C}$ whose weights are +1 and -1. It is then easy to calculate the variance of a two asset portfolio with the formula familiar from basic portfolio management courses:

$$
Var(\varepsilon_{A,B}) = Var(\varepsilon_{A,C}) + Var(\varepsilon_{B,C}) - 2\rho(\varepsilon_{A,C}, \varepsilon_{B,C}) * Var(\varepsilon_{A,C})^{1/2} * Var(\varepsilon_{B,C})^{1/2}
$$

Juggling the formula around brings us the correlation between two of the exchange rates:

$$
\rho(\varepsilon_{A,C}, \varepsilon_{B,C}) = \frac{Var(\varepsilon_{A,C}) + Var(\varepsilon_{B,C}) - Var(\varepsilon_{A,B})}{2 * Var(\varepsilon_{A,C})^{1/2} * Var(\varepsilon_{B,C})^{1/2}}
$$

If we now replace the variance estimates with option implied volatilities (and variances) we get the implied correlation:

$$
\rho_{IV}(\varepsilon_{A,C}, \varepsilon_{B,C}) = \frac{Var_{IV}(\varepsilon_{A,C}) + Var_{IV}(\varepsilon_{B,C}) - Var_{IV}(\varepsilon_{A,B})}{2 * Var_{IV}(\varepsilon_{A,C})^{1/2} * Var_{IV}(\varepsilon_{B,C})^{1/2}}
$$
SVENSK SAMMANFATTNING

11.1 Introduktion

Det senaste noggranna estimatet av volymen på valutamarknaden finns i publikationen av Bank of International Settlements (2014) där den dagliga volymen i april 2013 estimerades vara så mycket som 5 300 miljarder amerikanska dollar.

Intradagsvolatiliteten på valutamarknaden är i medeltal endast 1 %, som kan tolkas som 16 % annualiserat. Trots detta påminde schweiziska centralbankens beslut att tillåta valutan flyta normalt och händelserna i Ukraina om hur riskabel valutamarknaden kan vara. Företag som exporterade varor till Ryssland såg sin euronominerade försäljning minska i värde när EURRUB låg på 100,00 i december 2014. Bara tre månader tidigare låg EURRUB på 48,75. På motsvarande sätt fick schweiziska centralbankens beslut den 29 % intradagsrörelsen i EURCHF många schweiziska företag gå i kris endast på några minuter.


I denna avhandling studeras långfristiga konsekvenser av valutarisk inom företag genom att simulera värdet och lönsamheten av ett förenklat företag som endast har risk i valutan. Företagslogiken i simuleringen är byggd på redovisningsregler och rationella ledningsbeslut som siktar på att maximera företagets värde.

Undersökningen koncentreras på skillnader mellan beslut att inte skydda företaget mot valutarisk och att skydda mot risken med linjära och icke-linjära valutaskydd. Frågan om företag borde använda linjära eller icke-linjära valutaskydd har debatterats djupt och länge. Avhandlingen belyser ämnet genom att ta "going concern"-tänkandet med. Avhandlingen hämtar även nya argument till debatten om linjära och icke-linjära skydd och argumenterar för hur det kan vara suboptimalt för företag att använda icke-linjära skydd.
11.2 Syftet, avgränsningar och hypoteser

11.2.1 Avhandlingens syfte

Syftet med avhandlingen är att studera och numeriskt mäta hur interna asymmetrier inom företag kan förstärka effekten av valutarisk och vilka dess implikationer är för valutaskydd på lång sikt.

11.2.2 Restriktioner

Valutarisk begränsas så att den endast täcker avtalade och förväntade transaktionsrisker. Ekonomiska risken definierats brett som långfristig strategisk valutarisk exkluderas på grund av generella svårigheter att definiera risken och specifika svårigheter att mäta den. Translationsrisken exkluderas eftersom den påverkar företag på ett indirekt sätt och estimeringen av indirekta effekter är utanför avhandlingens syfte.

Eftersom undersökningen studeras med hjälp av en Monte Carlo-simulering kommer ett stort antal antaganden att introduceras. Dessa restriktioner diskuteras ingående i senare kapitel.

11.2.3 Hypoteser

Hypotes 1: Konkavitet i funktionen för investeringslönsamhet, konvexitet i skatter och konvexitet i kostnaden för externt kapital leder till att företag tappar värde på lång sikt även om valutarisken är perfekt symmetrisk.

Hypotes 2: Givet att det finns konkavitet i funktionen för investeringslönsamhet, konvexitet i skatter och konvexitet i kostnaden för externt kapital är icke-linjära valutaskydd suboptimala jämfört med linjära valutaskydd.
11.3 Motiveringar för valutaskydd


11.3.1 Skatter


I verkligheten är inte skattekonvexiteten så allvarlig på grund av att de flesta skatteavdrag tillåter olika underskottsavdrag som minskar problemet betydligt. Till exempel i Finland kan förluster användas i sju år för att minska kommande beskattade vinster (Skatteförvaltningen).

11.3.2 Investeringar

Investeringslönsamheten i företag brukar vara konkav i den investerade mängden. Förenklat betyder det att företag kan öka lönsamheten genom att investera mera, men lönsamheten ökar i avtagande takt. Inom nationalekonomin talar man om den avtagande marginella lönsamheten som säger att produktiviteten måste öka i avtagande takt om åtminstone en faktor är fast (Varian 2010). Ett exempel kan vara att företaget investerar i en större fabrik: Fabriken större ökar lönsamheten, men om utbudet av välutbildad arbetskraft inte är oändlig, måste lönsamheten börja avta i något skede.

11.3.3 Främmande kapital


Det främmande kapitalet orsakar även en mängd indirekta kostnader som endast sker när det främmande kapitalet ökar. Dessa indirekta kostnader har inte motsatta indirekta intäkter när företaget minskar på lånen. Till exempel företagets sannolikhet att gå i konkurs ökar när mängden lån ökar och detta leder till exempel till ökade lånekostnader. När företaget minskar lånemängden tillbaka till den optimala nivån kompenseras det däremot inte för de tilläggskostnader som det måste betala med högre hävstång (Jensen, Meckling (1976)).

11.3.4 Andra orsaker

11.4 Olika sätt att minska på valutarisk

Företag har i princip fyra olika alternativ att hantera valutarisk. Första alternativet är att inte skydda sig alls och hoppas på det bästa. Om man inte använder valutaskydd kan man antingen skydda sig med kassabuffert eller utan. Även om en kassabuffert inte i praktiken är ett valutaskydd så minskar det på effekterna av valutarisk. Om företaget däremot bestämmer sig för att skydda sig mot denna risk kan företaget göra det antingen med linjära eller icke-linjära finansiella kontrakt. Utöver dessa fyra alternativ kan företag även implementera så kallade operativa valutaskydd, men eftersom de ändrar på hela operationer i företaget diskuteras de inte här.

En kassabuffert låter kансke som en enkel lösning till variationen i kassaflöden, men eftersom det finns en alternativkostnad för pengar som ligger på kontot kan inte företag hålla allt för stor buffert. Därför måste lösningen till valutarisk ligga i finansiella kontrakt.


Ett motargument handlar om kassaflöden: Ett forwardkontrakt lämnar företaget opåverkat av den underliggande tillgången endast om företaget vet exakt när och hur stora dess framtida kassaflöden är i främmande valuta. I fall kassaflöden och skyddet inte motsvarar varandra kan företaget vara tvunget att betala stora summor för det finansiella kontraktet utan att ha motsatta kassaflöden från operationer. Optioner har inte samma problem eftersom optionskontrakt betalas på förhand.

Även om det finns många argument för båda kontrakten diskuteras det aldrig hur företagets interna processer kan påverka för- och nackdelarna med de två olika kontrakten. Senare i den här avhandlingen visas hur företagets interna processer kan vara ett argument för att använda linjära forwardkontrakt istället för icke-linjära optionskontrakt.
11.5 Tidigare forskning


FSS argumenterar däremot att samma inte kan hålla för företag eftersom valutarisk inte är symmetrisk för företag. Deras artikel bygger på en invecklad matematisk modell som antar att företag har en konkav investeringsfunktion och en konvex funktion för främmande kapital. Antaganden leder till en optimeringssituation där företaget kan öka på sitt värde genom att minska på variationen i kassaflöden. I fall variationen i kassaflöden är orsakade av valutarisk så kan valutaskydd öka på värdet av företaget.

Fast FSS motiverar för valutaskydd på grund av interna asymmetrier finns det ännu många öppna frågor som den här avhandlingen svarar på. Ena frågan är vad som händer företag på lång sikt. Det är klart att företag kan öka på det förväntade värdet för en period, men hurdan roll spelar ackumuleringen? Andra frågan gäller olika skyddsalternativ: Ifall företaget kan öka på sitt värde genom att minska på variationen i kassaflöden, fungerar linjära och icke-linjära valutakontrakt lika optimalt?
11.6 Empiriska undersökningen

Den här undersökningen baserar sig på en så kallad 'low-discrepancy Monte Carlo' simulering. Monte Carlo-simuleringar kan bäst förklaras med hjälp av sannolikhetslära: I sannolikhetslära är målet oftast att mäta relativ längd, yta eller volym. Man kan till exempel fråga vilken är sannolikheten att träffa mitt i prick på en piltavla i fall dess yta är en hundradel av hela tavlan yta. Man tolkar problemet med frågan: "Om jag har en pil och jag träffar tavlan, vad är sannolikheten att jag träffar mitt i prick?".

I en Monte Carlo-simulering vänder man om frågan. I stället för att svara på frågan om sannolikhet svarar man på frågan om ytor med hjälp av sannolikheter. I fall vi kastar tillräckligt många pilar på en tavla och vi vet hela tavlan yta kan vi räkna hur stor ytan av mitten är, baserat på sannolikheter. I fall man träffar mitten endast med var hundrade pil måste mitten vara 1/100 av hela ytan.


Simuleringen i den här undersökningen kallas för 'low-discrepancy Monte Carlo'-metod, eftersom olika iterationer i simuleringen inte är matematiskt sett stokastiska. Lagen om stora tal möjliggör det att man kan istället för slumpmässiga värden använda värden som beter sig som om de var slumpmässiga. Fördelen med 'low-discrepancy Monte Carlo' är att resultat konvergerar betydligt snabbare jämfört med vanliga Monte Carlo-metoder.

Företaget reagerar på variationen i kassaflöden genom att öka eller minska på mängden investeringar eller genom att öka på lån. Om företaget bestämmer sig för att lyfta lån så måste företaget betala direkta transaktionskostnader och det ökar på företagets lånekostnader. På grund av detta försöker företaget först minska på investeringarna. Företaget vill dock inte tillåta en förminskning i försäljningen och måste då ta lån om pengarna inte räcker till för att hålla investeringarna på en minimal nivå.

Företagsledningen tillåts också använda förluster för att minska på kommande års skattebörda. Ledningen använder möjligheten automatiskt och gör inte någon optimering i detta fall.
11.7 Resultat och konklusioner

Simuleringen tillåter att studera vilken som helst variabel inom företaget, men de viktigaste variablerna är företagets utbetalda dividender som mäter företagets förmåga att skapa värde för aktieägare och företagets tillväxttakt som mäter företagets hälsa.

När man jämför företagets förmåga att skapa värde eller tillväxt visar resultaten alltid samma ordning: Företaget får mest problem med valutor när det inte skyddar sig alls. Situationen är bättre för företaget som använder optioner, men för företaget som använder forwardkontrakt går det alltid bäst.

Resultaten är robusta och visar samma konklusioner oberoende av specifikationer i simuleringen eller val av de variabler som man följer.

En intressant detalj är att när man följer företagets behov av extern finansiering i det fall då företaget inte skyddar sig alls, så har företaget högst behov av kredit precis när tillången till kredit är sämst på den finansiella marknaden. Det betyder att problemen som företaget redan har med valutorna blir ännu värre när företaget måste konfrontera den omgivande ekonomin.

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