On the Management of Exchange Rate Risk

Maturity Effects, Country Effects, and Instruments

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> Referee: Prof. Dr. Olaf Korn Chair of Finance Georg–August–Universität Göttingen

Co-Referee: Prof. Dr. Markus Rudolf Dresdner Bank Chair of Finance WHU – Otto Beisheim School of Management

> Submitted by Dipl.-Wi.-Ing. Philipp Koziol

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Chapter 1

Introduction

Foreign exchange rate fluctuations represent a fundamental source of risk for international firms. Insufficient management of this risk can lead to extreme losses or even financial distress. In the past and especially in recent years, several examples of such immense losses occurred: The Japanese auto-manufacturer Mazda faced an operating loss of 16 billion Japanese Yen because of exchange rate losses on its European sales in 2001. Volkswagen's Fox production in Brazil burdened the company's 2005 operating profit with more than 200 million Euros because the Brazilian Real did not move in Volkswagen's favor. In 2006, currency effects caused losses of 666 million Euros for BMW. In addition to these company examples, the importance of Foreign Exchange (FX) risk for firms can be deduced from high trading volumes of FX derivatives,¹ which reached a notional value of almost 58 trillion US Dollars at the end of June $2007.^2$ As Berkman and Bradbury (1996) report, a large part of the growth in the derivatives markets is caused by corporations.³ Moreover, the tightening of international accounting regulations increases the importance of exchange rate management enormously and demands larger transparency in company reports.⁴ From the perspective of corporate law regulation, the Corporate Sector Supervision and Transparency Act (KonTraG), for example, became effective in 1998 in Germany and commits the boards of directors of listed companies to install a monitoring system

¹For this argument, see additionally: Bodnar, Hayt, and Marston (1998), the general study of Gebhardt and Ruß (1999), p. 42 f, and Bartram, Brown, and Fehle (2008).

²See Bank of International Settlements (2007).

³See also Buckley (1992).

 $^{^{4}}$ See IASB (2007).

for the early detection of developments that could endanger the future of the company as a going concern (§ 91 Abs. 2, AktG).⁵ Further, (1) the markets opened due to more liberal trade policies, (2) transportation costs were significantly reduced through technological innovations, (3) large currency blocs like China with their own, internally focused economic policies emerged, and (4), in general, the international involvement of firms increased immensely. The number of firms that are impacted directly or indirectly by currency risk has risen dramatically.

More than 30 years after the breakdown of the Bretton Woods system of fixed exchange rates, the literature on FX risk management is abundant and closely related to the evolution and development of the research on financial derivatives. However, only a few papers provide concrete, theory-based guidance for corporate risk management.

Existent literature comprises two major fields. The first addresses the fundamental necessity and motives for risk management on a corporate level, in general, without differentiating between the types of risk such as currency, interest rate, or commodity risk. On the one hand, it consists of theoretical explanatory approaches like (1) Stulz (1984), who discusses the manager's risk aversion, which is translated into the firm's risk aversion, (2) Smith and Stulz (1985), who stress direct and indirect bankruptcy costs, (3) Mayers and Smith (1982) and Ross (1996), who discuss tax advantages, and (4) Campbell and Kracaw (1990) as well as Froot, Scharfstein, and Stein (1993), who contribute studies on agency costs. On the other hand, there is a large number of empirical studies that test theoretical explanatory approaches like those of Howton and Perfect (1998), Haushalter (2000), Adam (2002), and Mahayni (2002). In addition, there are studies, that identify patterns of derivative usage, such as those by Brown (2001), Guay and Kothari (2003), and Judge (2006), and those which test the relation of firm value and derivative usage like Bartram (1999), Allayannis, Ihrig, and Weston (2001), and Niebergall (2008). Finally, this vein of literature includes those that examine the relation between FX changes/FX derivative usage and FX exposure, like Jorion (1990), Nydahl (1999), and Allayannis and Ofek (2001).

The second stream of literature covers the analysis of concrete hedging problems, as well as the determination of guidance for corporate risk management. In this

⁵For details on the KonTraG and its application in corporate practice, see Schitag Ernst & Young (1998), Emmerich (1999) as well as Wolf and Runzheimer (2003).

area, the works differ (1) in the decision criterion,⁶ which is often determined by certain utility functions⁷ or alternative approaches like value-at-risk, cash flow-at-risk, and earnings-at-risk,⁸ (2) in risk type such as exchange rate risk, interest rate risk, and commodity price risk which are often investigated separately,⁹ (3) in hedging instruments, such as forward contracts, futures, and options,¹⁰ and (4) in the time dimension, which can, on the one hand, be the difference between a one- and multi-period model or between a discrete and continuous-time approach or, on the other hand, the choice of hedge horizon.¹¹ The majority of approaches can be analyzed specifying these properties with respect to all possible characteristics.¹²

In this dissertation, we contribute to the second field of literature providing comprehensible theory-based practical implications for the management of exchange rate risk. In doing so, we shed light on (1) the aspect of time dimension concentrating on maturity effects, (2) the aspect of different hedging instrument usages, and (3) the aspect of special country effects, which induces particular conditions for FX hedging.

The present dissertation is organized as follows. The second chapter deals with the maturity effects of exchange rate risk management. Many firms face product price risk in foreign currency, stochastic costs in home currency, and exchange rate risk. If prices and exchange rates in different countries interact, natural hedges of foreign exchange risk may result. If the effectiveness of such hedges depends on the hedge horizon, they might affect a firm's usage of foreign exchange derivatives at different horizons and lead to a term structure of optimal hedge ratios. We analyze this issue by deriving the variance-minimizing hedge position in currency forward contracts within a basic

⁶Closely related to the decision criterion is the definition of risk which is often described with the exposure concept such as the transaction, translation, and economic exposure as discussed in Eiteman, Stonehill, and Moffett (2007). For their use, see Muller and Verschoor (2006) and Bartram (2008).

⁷For a general overview, see Huang and Litzenberger (1988). For an application of a general concave utility function, see Lapan, Moschini, and Hanson (1991) and for special utility functions, see Pfennig (1998).

⁸Studies that use these decision criteria are, for instance, Pritsker (1997), Ahn et al. (1999), and Muck and Rudolf (2004).

⁹Detailed studies of exchange rate risk management are done by Adam-Müller (1995), Pfennig (1998), and Breuer (2000).

¹⁰For the use of different contracts, see for instance, Adam-Müller (2000), Castelino (2000), and Brown and Toft (2002).

¹¹See, e.g., Adam-Müller (1995) for the use of one- and multi-period models.

¹²For numerous empirical studies of this area approximation or simulation methods are used. See Rudolf (2001) for an introduction to Monte Carlo simulation.

model of an exporting firm that is exposed to different risks. In an empirical study, we quantify the term structure of hedge ratios for a "typical" German firm that is exporting either to the United States (US), the United Kingdom (UK), or Japan (JP), using cointegrated vector autoregressive models of prices, interest rates, and exchange rates. We show that the hedge ratio decreases substantially with the hedge horizon, reaching values of one half or less for a ten-year horizon. Our findings not only explain the severe underhedging of long-term exchange rate exposures (at least partly) that is frequently observed but they also provide important implications for the design of risk management strategies.

In the third chapter, the usage of different instruments to hedge currency risk is investigated. Firms that export goods face risks such as product price risk, production cost risk, and exchange rate risk. As Chapter 2 shows, price and cost risks reduce FX hedging performance in real wealth. Thus, we investigate various hedging strategies that are purported to improve the performance of FX hedging in real terms using additional hedging instruments, such as inflation and interest rate derivatives, because they are closely related to changes in prices and costs. For this purpose, we derive variance-minimizing hedge positions in the currency derivatives and inflation or interest rate contracts of an exporting firm that is exposed to different risks in real wealth. Empirically, we again use a cointegrated vector autoregressive model of prices, interest rates, and exchange rates in order to quantify the hedge ratios and efficiencies of different hedging strategies for a German firm that exports to the US. Our main empirical results indicate that additional instruments can improve FX hedge performance immensely. For shorter hedge horizons, inflation derivatives are appropriate, but for longer hedge horizons, interest rate derivatives based on long-term interest rates perform best due to the integration and cointegration properties of prices and interest rates.

Chapter 4 investigates country effects in exchange rate risk management, using Poland as an example. The starting point is a simple model that is similar to those introduced in Chapters 2 and 3. The theoretical model considers a firm in three different cases that arise from certain production strategies. The firm sells its products in the domestic market, but it produces either in the home country or after relocation of production in a foreign country. Moreover, in one case, an FX hedge is applied. Equivalent to Chapters 2 and 3, we perform an empirical study to quantify currency risk for the different cases, considering a German firm. The foreign country for the cases of relocation of production is Poland, which exhibits special country effects since it suffered, on average, high inflation, and its currency was restricted by certain regimes. This study again specifies a cointegrated vector autoregressive model with possible cointegration relations between prices and the exchange rate. The results show that producing in a foreign country causes large currency risks that depend heavily on the time horizon. However, the "FOR+H" case demonstrates that hedging with an FX forward decreases currency risk substantially, even though a sizeable amount of currency risk remains due to high basis risks.

Chapter 5 concludes the dissertation and provides an outlook for possible future research.

Chapter 2

Maturity Effects: The Term Structure of Currency Hedge Ratios

2.1 Introduction

There is evidence that hedging strategies of non-financial firms strongly depend on the hedge horizon. One indication is taken from survey results by Bodnar, Hayt, and Marston (1996, 1998), who show that the percentage of firms using foreign currency derivatives decreases with the time to maturity of the contracts. Of all firms using derivatives, 82% hold at least some contracts with maturities less than 90 days, whereas only 12% hold any contracts with maturities greater than three years.¹ In this sense, we can speak of a decreasing term structure of hedging activity that might well translate into a corresponding term structure of hedge ratios. Such a term structure of hedge ratios is directly observed by Adam, Fernando, and Salas (2007). They show that the proportion of future production that is hedged decreases sharply with the hedge horizon for their sample of gold mining firms.

One can imagine different reasons why financial hedging activity declines with the hedge horizon. One important aspect is that operational hedges can be used instead of financial hedges to manage long-term exposure, as suggested by Brealey and Kaplanis

 $^{^1 \}mathrm{See}$ Bodnar, Hayt, and Marston (1998), p. 77 f.

(1995) and Chowdhry and Howe (1999).² In addition, long-term exposure might be hedged using dynamic strategies that employ short-term financial contracts. For example, Brennan and Crew (1997), Neuberger (1999), and Bühler, Korn, and Schöbel (2004) analyze different model-based strategies to hedge long-term commodity price exposure with short-term futures contracts.

We must also consider that the uncertainty of a firm's cash flows is likely to increase with the time horizon. For example, an exporting firm's revenues in foreign currency are probably better known for the next year than for the next five years. The theoretical literature on corporate risk management has shown that such revenue risk can cause underhedging of exchange rate risk, which could explain a downward sloping term structure of currency hedge ratios. For example, Benninga, Eldor, and Zilcha (1985) and Adam-Müller (1997) analyze hedging strategies with forward contracts. They show that if revenues and exchange rates are uncorrelated and forward markets are unbiased, underhedging occurs for utility functions with positive prudence.

A further explanation for underhedging of exchange rate risk at longer hedge horizons lies in certain imperfections in derivatives contracts, which become more relevant when the hedge horizon increases. One example are different forms of basis risk, as analyzed by Briys, Crouhy, and Schlesinger (1993), Castelino (2000), and Adam-Müller (2006). Furthermore, Castelino (2000) shows empirically that minimum-variance hedge ratios reduce with increasing basis risk. Another example is provided by increasing liquidity needs of long-term hedging strategies with futures contracts, as analyzed by Zhou (1998), Mello and Parsons (2000), and Deep (2002). Finally, Cummins and Mahul (2008) demonstrate that a possible default of over-the-counter (OTC) derivatives can lead to underhedging. Since default risk usually increases with the time to maturity, the extent of underhedging should increase with the hedge horizon.

In this chapter, we look at yet another aspect of the interplay between different sources of risk, the potential "natural hedging" of exchange rate risk by offsetting changes in a firm's revenues and costs. In the extreme case, if revenues move in parallel with the general price level and prices and exchange rates always follow the predictions of Purchasing Power Parity (PPP) theory, there will be a perfect natural hedge and the

²Allayannis, Ihrig, and Weston (2001), Kim, Mathur, and Nam (2006), and Bartram (2008) provide empirical evidence on the interplay between financial and operational hedging.

firm faces no exchange rate risk in real terms.³ However, this extreme case is surely not realistic, since a large body of literature has shown that PPP does not hold in the short run. Nevertheless, there is evidence for some movement towards PPP in the very long run.⁴ These findings suggest that the characteristics of exchange rate risk and hedge ratios depend on the hedge horizon. Even if PPP relations do not play any role, there might still be interactions between revenues, costs, and exchange rates which lead to hedge ratios that differ across hedge horizons.

The aim and contribution of this chapter is to show what the relations between revenues, costs, and exchange rates imply for corporate risk management. In essence, we characterize the term structure of currency hedge ratios, i.e., we ask how much should be hedged at different hedge horizons. In particular, the term structures of currency hedge ratios that we derive and quantify in this chapter help us shed light on two important issues. First, they provide evidence on how far the increased underhedging at longer hedge horizons, which we observe for many firms, can be explained by some kind of risk diversification between exchange rates and revenues. Second, they provide some guidance for risk managers to design hedging strategies in certain major currencies.

The starting point of our investigation is a simple model of an exporting firm that we use to derive the variance-minimizing hedge position in currency forward contracts. Based on this analysis, we perform an empirical study to quantify the term structure of currency hedge ratios and the corresponding hedging effectiveness for a German firm that exports either to the US, to the UK, or to Japan. This study specifies a vector autoregressive (VAR) model with possible cointegration relations between price levels, exchange rate, and long-term interest rates. By means of simulated sample paths from this model, generated by a bootstrap algorithm, we quantify hedge ratios and hedging effectiveness for different hedge horizons.

Our main empirical result shows that the term structure of hedge ratios is clearly decreasing for all currencies considered, going down to a half or less for a hedge horizon of ten years. One explanation is that revenue risk increases more strongly

³This argument is well known in the risk management literature. See, e.g., the critical discussion in Dufey and Srinivasulu (1983).

⁴The literature on PPP is enormous and we make no attempt to review it. Survey articles on this literature are Breuer (1994), Froot and Rogoff (1995), and Taylor and Taylor (2004).

with the hedge horizon than does exchange rate risk. The main reason, however, lies in the correlation structure between different risks that varies with the hedge horizon due to cointegration relations, i.e., we observe natural hedges at long horizons. As a consequence, hedging effectiveness decreases much less with the hedge horizon than hedge ratios.

For long horizons, there can also be substantial differences between currencies. For instance, the ten-year hedge ratio for the British Pound still amounts to 53% in comparison to 34% for the US Dollar. In contrast, the difference for shorter horizons of up to two years is very small.

The remaining part of the current chapter is organized as follows: Section 2 introduces the model of an exporting firm that hedges with forward contracts. We then derive the variance-minimizing hedge ratio and provide some interpretation. Section 3 contains the empirical study. First, the data-set is introduced and the study design is briefly explained. Then, we discuss the specification of the VAR model and report the cointegration results. Finally, the results on the term structure of hedge ratios and the hedging effectiveness of the corresponding strategies are presented and discussed. Section 4 completes Chapter 2 with a summary and a conclusion.

2.2 Model Analysis

2.2.1 Model Setup

Our analysis starts with a model of an exporting firm. This firm produces a single good that is sold in a foreign market. Assume that we are currently at time zero. In each of the following T periods, production takes place and goods are sold at the end of each period. Thus, the firm has a simultaneous exposure to foreign exchange risk at different horizons. For simplicity, assume that the firm has already decided on its per period output quantity, Q, which is constant over time.

Both the product prices \tilde{P}_t , t = 1, ..., T, in foreign currency and the corresponding exchange rates \tilde{X}_t , t = 1, ..., T, measured in units of home currency per unit of foreign currency, are exogenous stochastic variables. Since the firm produces in its home country, the exogenous stochastic production costs per period, \tilde{C}_t , t = 1, ..., T, are denominated in the firm's home currency. Therefore, the firm generates the following profits from operations per period:

$$\tilde{\Pi}_t = \tilde{P}_t Q \, \tilde{X}_t - \tilde{C}_t, \quad t = 1, \dots, T.$$
(2.1)

In a next step, the uncertainty in foreign revenues, costs, and exchange rates is specified more explicitly. Denote the current product price by P_0 and write the future product prices \tilde{P}_t , $t = 1, \ldots, T$, as

$$\tilde{P}_t = P_0(1 + \tilde{\epsilon}_{f,t}), \text{ with}$$

$$(1 + \tilde{\epsilon}_{f,t}) \equiv \prod_{k=1}^t (1 + \tilde{\epsilon}_{f,k-1,k}),$$

$$(2.2)$$

where $\tilde{\epsilon}_{f,k-1,k}$ is the uncertain percentage price change in period k. Note that this percentage price change equals the percentage change in revenues in foreign currency under our assumption of a fixed production quantity. In the same way, production costs in different periods are determined by some current cost level C_0 and the random percentage changes in costs, $\tilde{\epsilon}_{h,t}$, $t = 1, \ldots, T$:

$$\tilde{C}_t = C_0(1 + \tilde{\epsilon}_{h,t}), \quad \text{with}$$

$$(1 + \tilde{\epsilon}_{h,t}) \equiv \prod_{k=1}^t (1 + \tilde{\epsilon}_{h,k-1,k}).$$
(2.3)

The given representation of future prices and costs in terms of per period percentage changes is very useful later on. When we implement our model, we identify the changes in sales prices and revenues as changes in the foreign country's price level, and the changes in costs as changes in the home country's price level. Therefore, we implicitly assume that revenues and costs move according to the (production) price level. Although uncertainty in revenues and costs will usually have industry-specific and firm-specific components, our focus on the general price level provides a reference case that is useful in explaining "average" behavior of firms and provides a starting point for designing hedging strategies in specific situations. Let the uncertain future exchange rates \tilde{X}_t , $t = 1, \ldots, T$, be expressed as follows:

$$\tilde{X}_{t} = X_{0} \frac{(1 + \tilde{\epsilon}_{h,t})}{(1 + \tilde{\epsilon}_{f,t})} (1 + \tilde{u}_{t}), \quad \text{with}$$

$$(1 + \tilde{u}_{t}) \equiv \prod_{k=1}^{t} (1 + \tilde{u}_{k-1,k}).$$
(2.4)

Future exchange rates are functions of the current exchange rate X_0 and the random variables $\tilde{\epsilon}_{h,t}$, $\tilde{\epsilon}_{f,t}$, and \tilde{u}_t , $t = 1, \ldots, T$. Note that the formulation in Equation (2.4) does not impose any particular restrictions on the distribution of future exchange rates, since no assumptions are made about the distribution of the \tilde{u}_t s. Given our interpretation of $\tilde{\epsilon}_{h,t}$ and $\tilde{\epsilon}_{f,t}$ as relative price changes, \tilde{u}_t is the component of relative exchange rate changes that is not driven by relative price changes in the two countries. For example, with $\tilde{u}_t \equiv 0$, the exchange rate would exactly adjust in such a way that relative prices in the two countries are unchanged, i.e., relative PPP would hold. In this sense, the \tilde{u}_t s measure the deviations from relative PPP for different period lengths.

Substitution of Equations (2.2) to (2.4) into Equations (2.1) leads to the following perpendence period profits:

$$\hat{\Pi}_t = P_0 Q X_0 (1 + \tilde{\epsilon}_{h,t}) (1 + \tilde{u}_t) - C_0 (1 + \tilde{\epsilon}_{h,t}), \quad t = 1, \dots, T.$$
(2.5)

By summing these per period profits, we obtain the firm's profit from operations for the total period from zero to T, which is the assumed planning horizon. We have to consider, however, that some profits occur earlier than others. For reasons of tractability, we assume that the firm invests any early profits in real assets, whose value increases with the price level in the firm's home country, i.e., the real return is zero and the period k nominal compounding rate equals $\tilde{\epsilon}_{h,k-1,k}$. Under this assumption, the total profit from operations becomes

$$\tilde{\Pi} = \sum_{t=1}^{T} \left(\tilde{\Pi}_t \prod_{k=t+1}^{T} (1 + \tilde{\epsilon}_{h,k-1,k}) \right).$$
(2.6)

So far, hedging of exchange rate risk has not been considered. Assume now that the firm can enter into foreign exchange forwards with different maturity dates t = 1, ..., T at time zero. Denote by H_t the number of units of foreign currency *sold* for delivery at

time t and by $F_{0,t}$ the corresponding forward price. Then the total profit of the firm, including forward transactions, becomes

$$\tilde{\Pi} = \sum_{t=1}^{T} \left(\left[\tilde{\Pi}_t + H_t \left(F_{0,t} - \tilde{X}_t \right) \right] \prod_{k=t+1}^{T} (1 + \tilde{\epsilon}_{h,k-1,k}) \right).$$
(2.7)

In the next step, we exploit the covered interest parity relation to determine forward prices. Under standard assumptions, no-arbitrage prices of currency forward contracts are given by

$$F_{0,t} = X_0 \cdot \frac{(1+r_{h,t})}{(1+r_{f,t})}, \quad t = 1, \dots, T,$$
(2.8)

where $r_{h,t}$ and $r_{f,t}$ are the current t-period risk-free interest rates in the home country and the foreign country, respectively. Substituting the above expressions for the forward prices into Equation (2.7) and using the representation of future spot exchange rates \tilde{X}_t , $t = 1, \ldots, T$, from Equation (2.4), we finally obtain the following total profit:

$$\tilde{\Pi} = \sum_{t=1}^{T} \left(\left[\tilde{\Pi}_t + H_t X_0 \left(\frac{(1+r_{h,t})}{(1+r_{f,t})} - \frac{(1+\tilde{\epsilon}_{h,t})}{(1+\tilde{\epsilon}_{f,t})} (1+\tilde{u}_t) \right) \right] \prod_{k=t+1}^{T} (1+\tilde{\epsilon}_{h,k-1,k}) \right). \quad (2.9)$$

Investors are ultimately interested in consumption. Therefore, if the firm's nominal profit is high but the inflation rate is also high, investors might be worse off compared to a lower nominal profit in an environment with low inflation rates.⁵ Accordingly, we concentrate on real profits in our analysis, i.e., on profits in the firm's home currency measured in current prices. Equation (2.10) provides these real profits, which are obtained by dividing $\tilde{\Pi}$ from Equation (2.9) by $(1 + \tilde{\epsilon}_{h,T})$.

$$\tilde{\Pi}_{real} = \sum_{t=1}^{T} \left(P_0 Q X_0 (1 + \tilde{u}_t) - C_0 + H_t X_0 \left[\frac{(1 + r_{h,t})}{(1 + r_{f,t})} \frac{1}{(1 + \tilde{\epsilon}_{h,t})} - \frac{1}{(1 + \tilde{\epsilon}_{f,t})} (1 + \tilde{u}_t) \right] \right).$$
(2.10)

The real profit in Equation (2.10) provides the basis for the firm's hedging decision. As we can see, the risk of the firm's real operating profit depends only on the random variables $\tilde{u}_t, t = 1, \ldots, T$, the deviations from PPP. The risk of the forward positions,

 $^{^{5}}$ Adam-Müller (2000) uses the same argument and analyzes hedging strategies that consider real wealth instead of nominal wealth.

however, depends on both the deviations from PPP and the development of the price levels in the home country and the foreign country.

2.2.2 Hedging Strategy

The firm's hedging problem is to choose the optimal number of forward positions. Similar problems have been analyzed in the literature. A popular approach maximizes the expected utility of profits according to a concave utility function.⁶ In the context of this literature, profits according to Equation (2.10) resemble a hedging problem with both additive and multiplicative basis risk. Since general results are difficult to obtain in this case,⁷ we need additional restrictions on the decision criterion. Due to its tractability and popularity in practice, we use variance-minimization as the hedging goal.

To formulate the firm's decision problem, rewrite real profits as

$$\tilde{\Pi}_{real} = \sum_{t=1}^{T} \tilde{A}_t + H_t \tilde{B}_t, \text{ with}$$
(2.11)

$$A_t \equiv P_0 Q X_0 (1 + \tilde{u}_t) - C_0 \text{ and} \tilde{B}_t \equiv X_0 \left(\frac{(1 + r_{h,t})}{(1 + r_{f,t})} \frac{1}{(1 + \tilde{\epsilon}_{h,t})} - \frac{1}{(1 + \tilde{\epsilon}_{f,t})} (1 + \tilde{u}_t) \right).$$

The firm's decision problem can then be stated as:

$$\min_{H_t, t=1,\dots,T} Var\left[\sum_{t=1}^T \tilde{A}_t + H_t \tilde{B}_t\right].$$
(2.12)

Variance-minimization according to our setting is a standard optimization problem that leads to the necessary conditions for optimal forward positions given in the normal

⁶See, e.g., Holthausen (1979), Feder, Just, and Schmitz (1980), or Benninga, Eldor, and Zilcha (1984) for classical analyses based on one-period models.

⁷Briys, Crouhy, and Schlesinger (1993) determine some characteristics of the optimal forward position in the case of independent additive basis risk (Case A.2, p. 956 f.). Adam-Müller (2006) derives some results for independent multiplicative basis risk (Case M.2, Section 3). Note, however, that our hedging problem involves multiple forward contracts with different maturities and both additive and multiplicative basis risk. Moreover, it would be unreasonable to assume that the three random variables in Equation (2.10) are independent. Adam-Müller (2000) provides some results on underhedging and overhedging for the case of inflation risk in the home country. However, we consider inflation risk in both countries, the home country and the foreign country.

equations (2.13) below. These conditions are also sufficient for a unique minimum if the variance-covariance matrix of the \tilde{B}_t s, t = 1, ..., T, has full rank, i.e., if none of the forward contracts is a redundant hedging instrument.

$$\sum_{i=1}^{T} Cov[\tilde{A}_i, \tilde{B}_t] + H_i Cov[\tilde{B}_i, \tilde{B}_t] \stackrel{!}{=} 0, \quad t = 1, \dots, T.$$
(2.13)

Solutions to the system of linear equations (2.13) can easily be computed numerically if the necessary variances and covariances are available. As we see from the optimality conditions, the hedge positions depend on all covariances between the profits from operations in different periods (\tilde{A}_t s) and the payoffs of different forward contracts (\tilde{B}_t s). Moreover, all covariances between the \tilde{B}_t s enter into the calculation of the forward positions. Note, however, that the optimal forward positions do not depend on the initial cost C_0 and the initial exchange rate X_0 . The cost C_0 is an additive non-random term in the profit function, which does not influence the variance of total profits. The initial exchange rate X_0 is just a multiplicative scaling factor that scales all relevant random components of both the \tilde{A}_t s and the \tilde{B}_t s.

The optimization problem (2.12) exploits the complete dependence structure between operating profits in different periods and forward contracts with different maturities. In principle, the approach allows for a general cross hedging between different maturities, i.e., long-term exposure might be hedged to some extent with short-term forwards and short-term exposure to some extent with long-term forwards. However, the information requirements that make such a general cross hedge possible and useful are quite demanding.⁸ Moreover, one would expect that the resulting strategies are very sensitive to specification errors with respect to the input parameters⁹ because of near multicollinearity between forward contracts written on the same underlying. As a consequence, the resulting hedge positions might be hard to interpret economically and difficult to communicate to the management. Therefore, many firms quantify their foreign exchange exposure separately for different time horizons and use maturity

⁸For example, the study by Loderer and Pichler (2000) indicates that one should not be too optimistic about the available information. Their survey results for Swiss firms show that many firms were not even able to quantify their currency risk exposure.

⁹Input parameters are the required variances and covariances. As these moments usually have to be estimated, estimation errors are likely.

matching contracts to hedge exposure.¹⁰ This more realistic approach is also followed here. In our setting, it leads to the restriction that profits occurring at time t are hedged exclusively with forwards maturing at time t. Under this restriction, hedging problem (2.12) leads to the following first order conditions:

$$Cov[\tilde{A}_t, \tilde{B}_t] + H_t Cov[\tilde{B}_t, \tilde{B}_t] \stackrel{!}{=} 0, \quad t = 1, \dots, T.$$

$$(2.14)$$

Solving for the H_t s delivers the following optimal forward positions:

$$H_t^* = -\frac{Cov[\tilde{A}_t, \tilde{B}_t]}{Var[\tilde{B}_t]}, \quad t = 1, \dots, T.$$

$$(2.15)$$

Finally, we can substitute for A_t and B_t in the above equations. As a result, we obtain the following representation of the hedge positions:

$$H_t^* = -\frac{Cov\left[P_0 Q\left(1+\tilde{u}_t\right), \frac{(1+r_{h,t})}{(1+r_{f,t})} \frac{1}{(1+\tilde{\epsilon}_{h,t})} - \frac{1}{(1+\tilde{\epsilon}_{f,t})}(1+\tilde{u}_t)\right]}{Var\left[\frac{(1+r_{h,t})}{(1+r_{f,t})} \frac{1}{(1+\tilde{\epsilon}_{h,t})} - \frac{1}{(1+\tilde{\epsilon}_{f,t})}(1+\tilde{u}_t)\right]}, \quad t = 1, \dots, T.$$
(2.16)

To get some intuition for the optimal forward positions H_t^* , it is instructive to look at some extreme cases. Firstly, consider that relative PPP holds exactly, which implies that $Var(\tilde{u}_t) = 0$ for all t. Then, the \tilde{A}_t s would not be stochastic and doing without forward contracts would lead to a total variance of zero. This "no hedge" result is quite intuitive. If PPP holds, the firm faces no risk in real operating profits. Therefore, hedging is not needed. On the contrary, since forwards are written on the nominal exchange rate, hedging would introduce risk in the first place.

A second extreme case would consider non-stochastic product prices and costs, i.e., $Var(\tilde{\epsilon}_{h,t}) = Var(\tilde{\epsilon}_{f,t}) = 0$ for all t. Under this assumption, we can see from Equations (2.16) that we obtain forward positions $H_t^* = P_0 Q (1 + \epsilon_{f,t})$. Such forward positions represent a "full hedge". Note that revenues at time t in foreign currency equal $P_0 Q (1+\epsilon_{f,t})$. These revenues are fully hedged with the corresponding currency forward contracts. The following intuition lies behind this result: If movements of the price level in both countries are deterministic, the only remaining source of risk is \tilde{u}_t , the deviation from relative PPP. Accordingly, since currency risk is completely independent

¹⁰See Brown (2001), p. 411, for an example of such a procedure.

of the relative price levels, there is no natural hedge component and the firm's foreign currency position should be fully hedged in the forward market. Such a full hedge would eliminate risk completely.

Irrespective of whether PPP holds or not, the two extreme cases highlight the fact that the term structure of hedge positions will strongly depend on how different sources of risk scale with the hedge horizon. If the "price risks" $\tilde{\epsilon}_{h,t}$ and $\tilde{\epsilon}_{f,t}$ increase more strongly with the hedge horizon than the "real exchange rate risk" \tilde{u}_t , hedging becomes less and less attractive, since forward contracts enhance the first kind of risk and reduce the second one. Thus, the term structure of hedge positions is expected to fall. In addition, the correlation structure of the "price risks" and the "real exchange rate risk" could change with the hedge horizon, which is a second channel by which the term structure of hedge positions could be influenced.

Usually, one analyzes hedging strategies in terms of hedge ratios, normalized values that are often easier to interpret and to compare. Within our model, the hedge ratios for hedge horizons t = 1, ..., T are reasonably defined as the ratios of H_t^* and the expected revenues at time t in foreign currency, $P_0 Q E(1+\tilde{\epsilon}_{f,t})$. This kind of normalization leads to the following expressions for the optimal hedge ratios:¹¹

$$HR_{t}^{*} = -\frac{Cov\left[\left(1+\tilde{u}_{t}\right), \frac{\left(1+r_{h,t}\right)}{\left(1+r_{f,t}\right)} \frac{1}{\left(1+\tilde{\epsilon}_{h,t}\right)} - \frac{1}{\left(1+\tilde{\epsilon}_{f,t}\right)}\left(1+\tilde{u}_{t}\right)\right]}{E\left(1+\tilde{\epsilon}_{f,t}\right)Var\left[\frac{\left(1+r_{h,t}\right)}{\left(1+r_{f,t}\right)} \frac{1}{\left(1+\tilde{\epsilon}_{h,t}\right)} - \frac{1}{\left(1+\tilde{\epsilon}_{f,t}\right)}\left(1+\tilde{u}_{t}\right)\right]}, \quad t = 1, \dots, T.$$
(2.17)

The term structure of currency hedge ratios, i.e., the hedge ratios for different hedge horizons t from Equation (2.17), will be quantified for different currencies in our empirical study. Note that the hedge ratios do not depend on the quantity Q and the current product price P_0 . They are solely determined by the current interest rates $r_{h,t}$ and $r_{f,t}$ and the joint distributions of the three groups of random variables $\tilde{\epsilon}_{h,t}$, $\tilde{\epsilon}_{f,t}$, and \tilde{u}_t .

A comparative static analysis with respect to one of the moments of $\tilde{\epsilon}_{h,t}$, $\tilde{\epsilon}_{f,t}$, and \tilde{u}_t does not in general lead to a distinct conclusion, since all random variables can be arbitrarily correlated. However, we can get some intuition about the effects of a higher price risk in the home country $(\tilde{\epsilon}_{h,t})$, a higher price risk in the foreign country

¹¹Note that the second extreme case from above leads to a hedge ratio of one, which is intuitive.

 $(\tilde{e}_{f,t})$, and a higher risk of a deviation from PPP (\tilde{u}_t) if we assume independence of the three random variables. Firstly, if the price level in the home country gets more volatile, the numerator in Equation (2.17) does not change, but the denominator increases. Therefore, the hedge ratio decreases. Second, if the volatility of prices in the foreign country increases (without changing first moments), a similar effect results. The numerator of the hedge ratio stays the same, the denominator increases, and the hedge ratio decreases. Finally, an increased volatility of \tilde{u}_t increases both the covariance in the numerator of the hedge ratio and the variance in the denominator. However, if the random variable $1+\tilde{e}_{f,t}$ is greater than one, i.e., if the inflation rate is positive, the effect on the numerator will dominate and the hedge ratio increases. Roughly speaking, we can conclude that a higher inflation risk decreases hedge ratios, while a higher inflation independent currency risk increases hedge ratios. At the limits, we reach the no hedge case and the full hedge case, respectively.

2.3 Empirical Study

2.3.1 Study Design and Data-Set

In our model, the currency specific hedge ratios HR_t^* , $t = 1, \ldots, T$, depend crucially on the joint distribution of the three groups of random variables: $\tilde{\epsilon}_{h,t}$, $\tilde{\epsilon}_{f,t}$, and \tilde{u}_t . Thus, an econometric model which quantifies the joint distribution at different time horizons is required. In particular, we need an econometric model that realistically captures the dynamics of prices and exchange rates. A typical framework for such an analysis is a cointegrated VAR model. When modeling prices and exchange rates in such a framework, one usually includes interest rates as well because of the strong economic connection between inflation, exchange rates, and interest rates.¹² We follow the same approach, since the moments that make up the hedge ratios HR_t^* should be interpreted as conditional moments, and interest rates are potentially important conditioning variables.

Based on a specified and estimated VAR model for two countries, the required moments of the random variables $\tilde{\epsilon}_{h,t}$, $\tilde{\epsilon}_{f,t}$, and \tilde{u}_t , $t = 1, \ldots, T$, are quantified using a bootstrap

¹²See Juselius and MacDonald (2000, 2004).

algorithm. In this algorithm, we resample residual vectors and construct simulated paths of the corresponding variables for time horizons of up to ten years. From these simulated paths we obtain hedge ratios HR_t^* by calculating the realized moments according to Equation (2.17).

The data-set used for the estimation of the cointegrated VAR model was retrieved from the International Financial Statistics (CD ROM, 3/2006) of the International Monetary Fund (IMF) and the Datastream database. It consists of monthly price levels, interest rates, and exchange rates for Germany, the US, the UK, and Japan over the period from July 1975 to December 2005. The data period of more than 30 years leaves us with a total number of 366 observations for each data series. Data before 1975 were not taken into account to avoid any influence of the Bretton Woods system of fixed exchange rates. As proxies for product prices and costs we use producer price indices (PPI), which are more appropriate than consumer price indices. Prices in the foreign country and in the home country (Germany) are denoted by P_f and P_h , respectively. The corresponding logarithmic prices are p_f and p_h . The level of the exchange rate (end-of-month rates) between Germany and the foreign country is denoted by X, and the logarithmic exchange rate by x. Before 1999, synthetic exchange rates for the Euro are used, which were calculated using the introductory rate of the Euro to the Deutschmark (DM). Finally, we use long-term government yields as interest rates in the econometric model, which are denoted by i_f^l and i_h^l .

Figures 2.4 to 2.7 in the Appendix give an overview of the time series underlying our analysis. The figures strongly indicate that the series are non-stationary. The degree of integration of different series and possible cointegration relations between different series are very important for the term structure of hedge ratios. Therefore, these properties will be carefully considered in the concrete specification of the econometric model.

Additionally, for the risk-free interest rates $r_{h,t}$ and $r_{f,t}$, which are necessary to determine the FX forward prices according to Equation (2.8), we use the interpolated zero curve yield calculated from swap rates for the respective maturity and country, obtained from Datastream.

2.3.2 Specification of the VAR Model

A p-dimensional cointegrated VAR model with l lags, stated in vector error correction (VEC) form, is defined as follows:

$$\Delta Y_t = \Gamma_1 \Delta Y_{t-1} + \ldots + \Gamma_{l-1} \Delta Y_{t-l+1} + \Pi Y_{t-1} + \Phi D_t + \xi_t, \ t = 1, \ldots, \widehat{T},$$
(2.18)

where Y_t is a p-dimensional random vector of endogenous variables, Π and $\Gamma_1, \ldots, \Gamma_{l-1}$ are $p \times p$ coefficient matrices, D_t is a b-dimensional vector of deterministic components like a constant, a linear time trend, seasonal or intervention dummies etc., Φ is a $p \times b$ coefficient matrix and ξ_t , $t = 1, \ldots, \hat{T}$, are p-dimensional vectors of i.i.d. Gaussian error terms. In an I(1) cointegrated VAR model with r linearly independent cointegration equations, the long-run matrix Π can be written as

$$\Pi = \alpha \beta', \tag{2.19}$$

where α and β are $p \times r$ coefficient matrices with full column rank and $r \leq p$. As the vector time series Y_t , $t = 1, \ldots, \hat{T}$, is assumed to be I(1), its first difference, ΔY_t , is stationary. In this sense, the matrix Π transforms non-stationary series into stationary ones. In particular, the matrix β contains the weights of the stationary linear combinations of the I(1) vector time series Y_t , $t = 1, \ldots, \hat{T}$, and the matrix α contains the parameters that determine the speed of adjustment to the long-run equilibrium relations.

In the econometric model that we apply to characterize the term structure of currency hedge ratios, the vector Y_t consists of five variables. First, (monthly) inflation rates Δp_h and Δp_f are used to represent the uncertainty of revenues and costs in the model. The part of exchange rate uncertainty that cannot be explained by price changes is captured by the deviation from *absolute* PPP, which is given by $ppp \equiv p_h - p_f - x$.¹³ Note that the moments of the three groups of random variables that enter into the hedge ratios according to Equation (2.17) should be conditional moments. Since interest rates are

 $^{^{13}}$ According to Equation (2.18), changes of this variable are simulated later, which capture deviations from *relative* PPP, i.e., changes in real exchange rates. The time series behavior of *ppp* is shown in Figure 2.8 in the Appendix.

natural conditioning variables for the interplay between prices and exchange rates, they are additionally included. In summary, the vector Y_t takes the following form:¹⁴

$$Y_{t} = \begin{pmatrix} ppp_{t} \\ \Delta p_{f,t} \\ \Delta p_{h,t} \\ i_{f,t}^{l} \\ i_{h,t}^{l} \end{pmatrix}.$$
(2.20)

The integration rank of each of the above time series is determined by means of standard unit root tests. The first test that we apply is the Augmented Dickey Fuller (ADF) test¹⁵, which has a null hypothesis of non-stationarity. The second one is the test by Kwiatkowski et al. (1992) (KPSS), which has a null hypothesis of stationarity. The test results of Table 2.1 indicate that all time series are best described as I(1) processes. A graphical inspection of the series confirms these results, which are in line with results of similar analyses in the literature.¹⁶ In particular, note that we do not find evidence for stationarity in the three *ppp* series. Thus, we have to conclude that PPP in the sense of mean-reversion towards the PPP relation does not hold.

In the next step of model specification, we have to choose the lag lengths of our three VAR models (US, UK, JP). A choice of two lags is supported by the information criteria of Hannan-Quinn and Schwarz, as given in Table 2.2. The only exception is a lag length of one for the UK, according to the Schwarz criterion. However, since a lag length of one leaves us with some autocorrelation in the residuals,¹⁷ we choose two lags.¹⁸

The graphs of the differenced variables in the Appendix show that the normality assumption is not valid for many of the marginal processes. To obtain valid statistical inference, we need to control for possible intervention effects. Thus, an unrestricted

¹⁴Centered seasonal dummies are used to capture seasonal effects in the data, because the time series are not seasonally adjusted.

 $^{^{15}}$ See Dickey and Fuller (1979, 1981) and Said and Dickey (1984).

¹⁶See Juselius and MacDonald (2000, 2004).

¹⁷Corresponding results of an LM test are not reported here.

¹⁸See also Juselius (2006), p. 72, who stresses that a model with two lags is often the best starting point.

	ADF test	KPSS test
$\overline{\Delta p_h}$	-2.676^{*}	0.600^{**}
Δp_{US}	-2.280	0.556^{**}
Δp_{UK}	-1.953	2.698^{***}
Δp_{JP}	-2.544	0.667^{**}
ppp_{US}	-1.929	0.383^{*}
ppp_{UK}	-2.143	1.978^{***}
ppp_{JP}	-2.386	1.266^{***}
i_h^l	-1.310	2.359^{***}
i_{US}^l	-1.047	2.764^{***}
i_{UK}^l	-1.250	3.827^{***}
i_{JP}^l	-1.422	3.653^{***}

Note: For the ADF tests, *, **, and *** mean that the null hypothesis of non-stationarity is rejected at a confidence level of 90%, 95%, and 99%. The corresponding critical values are -3.451, -2.870, and -2.571 assuming no linear trend. For the KPSS tests, *, **, and *** mean that the null hypothesis of stationarity is rejected at a confidence level of 90%, 95%, and 99%. The lag truncation parameter is set to 8 according to Kwiatkowski et al. (1992), p. 174, since at this value the test settles down. The critical values are 0.347, 0.463, and 0.739 assuming no linear trend in the data.

Table 2.1: Unit root tests.

constant¹⁹, some additive outlier corrections²⁰, innovational dummies²¹, and level shift dummies²² are included.²³

In a next step, the cointegration rank r is determined. Results of the trace test, or Johansen test, are reported in Table 2.3.²⁴ Table 2.3 clearly shows that for every country the largest two eigenvalues are significantly different from zero. The

¹⁹In this way, a trend in levels, but not in differences, is allowed, which matches the behavior of the underlying processes.

²⁰Additive outliers strongly indicate measurement errors and were removed from the time series of the inflation rates in January, 2001, January, 2003, and January, 2005, for Germany and in January, 2003, March, 2003, and January, 2004 for the US.

²¹Unrestricted permanent and transitory intervention dummies are used if a residual larger than $|3.81 \sigma_{\xi}|$ can be related to a known intervention.

²²The level shift dummies are included in the cointegration space and in first differences outside the cointegration relations. In the US model there are level shift dummies in January 1982 and March 1999, in the UK model in August 1982 and April 1985, and in the JP model in January 1982 and April 2000.

²³A detailed description of the dummies is available from Tables 2.9, 2.10, and 2.11 in the Appendix.

²⁴Since our models contain level shifts that create shifts in the asymptotic distributions, the critical values of the test statistics were simulated using 1,000 random walks and 10,000 replications for each country.

	Information criterion	VAR(1)	VAR(2)	VAR(3)	VAR(4)	VAR(5)
\mathbf{US}	Schwarz	-70.819	-70.835	-70.524	-70.229	-69.926
	Hannan-Quinn	-72.120	-72.299	-72.149	-72.017	-71.877
UK	Schwarz	-72.049	-72.046	-71.755	-71.423	-71.179
	Hannan-Quinn	-73.187	-73.347	-73.218	-73.048	-72.967
$_{\rm JP}$	Schwarz	-72.552	-72.568	-72.333	-71.996	-71.675
	Hannan-Quinn	-73.885	-74.063	-73.991	-73.817	-73.658

Table 2.2: Determination of the lag length.

significance of the third eigenvalue is a borderline case. For the US and the UK, the trace test suggests two cointegration relations between the endogenous variables. For Japan, it indicates three cointegration relations. However, an inspection of the third cointegration relation and the number of roots of the companion matrix²⁵ in Table 2.4 do not support a cointegration rank of r = 3. If the cointegration rank was three, the companion matrix would have only two roots close to unity. However, in the case of Japan, there are clearly three roots close to unity. Accordingly, we stay with a cointegration rank of two for each of the three models.

To check the assumptions of the standard I(1) approach, we applied several misspecification tests to the estimated cointegrated VAR models. The results of these tests are presented in Table 2.5. The multivariate LM test statistics for first and second order residual autocorrelation are not significant at the 5% level, so, importantly, the property of no autocorrelation is not rejected. Table 2.5 additionally shows that multivariate normality is clearly violated. Since the univariate misspecification tests, which are not reported here, indicate that the rejection of normality results from excess kurtosis and not skewness, non-normality is a less serious problem for the estimation results. With respect to autoregressive conditional heteroskedasticity (ARCH) effects, we find that only for the US model the multivariate LM test does not reject the hypothesis of no ARCH effects on typical significance levels. Furthermore, as shown by Rahbek, Hansen, and Dennes (2002), the cointegration rank tests are robust against moderate residual ARCH effects. Finally, we performed tests on parameter constancy.

 $^{^{25}}$ See Juselius (2006), p. 50 ff.

	p-r	r	Eig.Value	Trace	Trace*	Frac95	P-Value	P-Value*
US	5	0	0.348	258.471	252.609	53.956	0.000	0.000
	4	1	0.208	103.230	101.132	35.098	0.000	0.000
	3	2	0.036	18.744	18.357	20.604	0.088	0.098
	2	3	0.009	5.437	5.117	9.964	0.252	0.281
	1	4	0.006	2.097	1.653	0.000	NA	NA
UK	5	0	0.341	278.597	272.228	65.550	0.000	0.000
	4	1	0.242	127.213	124.521	45.380	0.000	0.000
	3	2	0.034	26.810	26.275	28.317	0.075	0.085
	2	3	0.024	14.073	13.072	14.465	0.062	0.086
	1	4	0.015	5.305	4.637	3.799	0.021	0.031
$_{\rm JP}$	5	0	0.312	278.198	271.945	76.655	0.000	0.000
	4	1	0.240	142.265	138.979	53.825	0.000	0.000
	3	2	0.073	42.568	41.480	34.482	0.006	0.008
	2	3	0.026	14.867	13.347	18.984	0.159	0.231
	1	4	0.014	5.135	4.797	6.048	0.077	0.091

Note: *=trace test statistics and p-values are based on the Bartlett small-sample correction.

Table 2.3: Rank determination tests (trace tests).

The results support the constancy of the parameters in the chosen reduced rank VAR models. After having specified the VECMs and having checked all the assumption of the I(1) model, we obtain three models of the dynamics of prices, interest rates, and exchange rates. The parameter estimates of these country-specific VECMs are presented in Tables 2.12, 2.13, and 2.14 in the Appendix. A general look at the three models shows that they are not only well specified from an econometric point of view, but are also economically reasonable in the sense that in almost all cases the signs of the estimated coefficients are plausible.

Country	Rank	ρ_1	ρ_2	$ ho_3$	$ ho_4$	$ ho_5$
US	r = 1	1	1	1	1	0.364
	r = 2	1	1	1	0.375	0.375
	r = 3	1	1	0.934	0.368	0.358
UK	r = 1	1	1	1	1	0.380
	r = 2	1	1	1	0.453	0.453
	r = 3	1	1	0.96	0.545	0.545
$_{\rm JP}$	r = 1	1	1	1	1	0.627
	r = 2	1	1	1	0.742	0.522
	r = 3	1	1	0.948	0.741	0.420

Table 2.4: Modulus of the five largest roots of the companion matrix for different cointegration ranks.

	\mathbf{US}	$\mathbf{U}\mathbf{K}$	$_{\rm JP}$
Tests for autocorrelation:			
LM(1)	0.136	0.198	0.075
LM(2)	0.055	0.543	0.252
Test for Normality	0.000	0.000	0.000
Tests for ARCH:			
LM(1)	0.041	0.001	0.00
LM(2)	0.409	0.001	0.00

Table 2.5: Misspecification tests: p-values of the corresponding test statistics.

2.3.3 Results: Hedge Ratios and Hedging Effectiveness

The VECMs that we have specified in the previous subsection can now be used to quantify the term structure of currency hedge ratios. The resulting variance-minimizing hedge ratios HR_t^* according to Equation (2.17) for different countries and different hedge horizons are shown in Table 2.6 and Figure 2.1.

	1 month	6 months	1 year	2 years	5 years	10 years
US \$	0.97	0.93	0.89	0.83	0.64	0.34
$\mathbf{U}\mathbf{K}\pounds$	0.99	0.96	0.92	0.86	0.71	0.53
$\rm JP~{\bf \xi}$	0.99	0.96	0.93	0.87	0.73	0.52

Table 2.6: Hedge ratios HR_t^* for different hedge horizons.



Figure 2.1: The term structure of currency hedge ratios.

The table and the figure provide several interesting results. First, the term structure of hedge ratios clearly decreases. Second, hedge ratios are still close to one for shorter hedge horizons of up to one year. Third, the hedge ratios lie substantially below one for hedge horizons of five years or longer for all three currencies. For a hedge horizon of ten years, values drop down to about one third (US Dollar) or about one half (British Pound and Japanese Yen). Finally, for very long hedge horizons, there can be
clear discrepancies between the forward positions in the three currencies, i.e., different currencies should be hedged differently.

These results have important practical implications. Seen from one perspective, we could say that they indicate the existence of dependencies between revenues, costs, and exchange rates over longer periods, which make long-term hedging with currency forwards less important. The quantitative effects of these dependencies or natural hedges can be substantial for exposures that lie several years in the future. For shorter time periods, however, like the next one or two years, one should not rely too much on these natural hedges and use an almost full hedge with forward contracts.

Seen from another point of view, we could say that hedges lose attractiveness and effectiveness due to unhedgable risks, which result from uncertain revenues and costs. As these unhedgable risks get more and more important for longer hedge horizons, we should hedge less and less.

In order to get a better understanding of our results and their different interpretations, we have to take a closer look at the driving forces that lie behind them. Our first interpretation of the downward sloping term structure of hedge ratios, the importance of natural hedges, is closely linked to the observation that relevant risk factors enter into cointegration relations, which in turn make the correlation structure a function of the hedge horizon. Figure 2.2 shows these effects.

Going back to the forward positions in the real profit equation (2.10), we see that revenue risk $(1/(1 + \tilde{\epsilon}_{f,t}))$ and real exchange rate risk $(1 + \tilde{u}_t)$ are connected in a multiplicative way. Therefore, the firm's hedging strategy crucially depends on the correlation between these two risk factors. A strong positive correlation implies that forwards are effectively more sensitive to changes in real exchange rates than real profits are. Accordingly, a variance-minimizing strategy would require a lower usage of forward contracts if the correlation were higher. Figure 2.2 shows that such an effect is very relevant for our results. The crucial correlation between $(1/(1 + \tilde{\epsilon}_{f,t}))$ and $(1 + \tilde{u}_t)$ increases steadily with the hedge horizon for all three currencies, reaching values of 60 percent or more.

The second interpretation of the downward sloping term structure, the increasing importance of unhedgable risks, corresponds to the observation that prices follow I(2) processes, but exchange rates (and deviations from PPP) follow I(1) processes. The



Figure 2.2: Correlations between risk factors.

relative increase in variance of I(2) processes with the hedge horizon is much stronger than the relative increase in variance of I(1) processes. As Figure 2.3 shows for the risk factors of our model, we observe a linear function (I(1) process) in contrast to an exponential one (I(2)). Therefore, both the proportion of hedgable risks and the hedge ratios should decrease with the hedge horizon.

In summary, the interplay of two effects – the different degrees of integration of different risk factors and the cointegration relations between them – drives our results on the downward sloping term structure of hedge ratios. This finding highlights the importance of capturing the integration and cointegration properties adequately. Also



Figure 2.3: Variances of risk factors.

note that a movement of two countries towards PPP is not necessarily a pre-requisite for a downward sloping term structure of hedge ratios. Even if the deviation from PPP is an I(1) process, we might still have price risks that increase even more with time and therefore lead to declining hedge ratios.

Our two explanations for a downward sloping term structure of hedge ratios, natural hedges and unhedgable risks, have quite different implications for the risk management strategies of firms. If the effects were completely driven by natural hedges, one would not observe a strong decrease in hedging effectiveness with the hedge horizon. Hedging with forwards should be reduced for longer horizons, but the overall risk reduction would be sufficient. To the contrary, if unhedgable risks were the dominant reason for an increased underhedging, hedging effectiveness would deteriorate dramatically with the hedge horizon. In such a situation, financial hedging alone would not be sufficient to reduce risk and the firm should think about supplementary measures, like operational hedging.

In order to judge the quantitative importance of the two different reasons for a downward sloping term structure, we take a look at the hedging effectiveness. The hedging effectiveness can be measured by the percentage variance reduction of the hedge, the Johnson measure,²⁶ that is formally defined as

$$JM \stackrel{\circ}{=} Percentage in Variance Reduction = \frac{Var(unhedged position) - Var(hedged position)}{Var(unhedged position)}.$$
 (2.21)

To get a general impression of the hedging effectiveness that can be achieved, let us look at a firm that sells one unit of its product in each of the following ten years and consider the variance reduction of real profits over the total ten-year period. The second column of Table 2.7 provides the corresponding results for all three currencies. As we see, variance reduction is highest for the British Pound and lowest for the US Dollar, which might be due to the closer link between the United Kingdom and Germany as members of the European Union. Most interestingly, however, we see that hedging effectiveness is generally very high for all countries, achieving a risk reduction of 89% or more.²⁷

Even though the "average" variance reduction of all exposures that a firm faces over a ten-year period is high, it is instructive to check how effectively single exposures at certain times in the future can be hedged. Such maturity specific measures of hedging effectiveness are shown in the third to eights column of Table 2.7.

As we see, hedging effectiveness decreases with the hedge horizon. However, the decrease is much smaller than the decrease in hedge ratios. Take the results for the

 $^{^{26}\}mathrm{See}$ Johnson (1960).

²⁷Note that a strategy that allows for a general cross hedging between different maturities and exploits all covariances between operating profits and forward contracts of all maturities improves the hedging effectiveness only marginally. The corresponding variance reductions are 88.9% for the US, 97.9% for the UK, and 95.6% for Japan. These results provide a further argument for the use of a maturity matched hedging strategy.

JM	1-10 years	1 month	6 months	1 year	2 years	5 years	10 years
US \$	0.886	0.979	0.974	0.972	0.964	0.913	0.771
$\mathbf{U}\mathbf{K}$ £	0.963	0.983	0.982	0.982	0.980	0.963	0.923
$\rm JP~{\bf F}$	0.948	0.991	0.985	0.982	0.978	0.956	0.904

Table 2.7: Comparison of hedging performance using the Johnson measure.

British Pound, for example. Hedge ratios decrease substantially from 99% (hedge horizon of one month) to 53% (hedge horizon of ten years), whereas the variance reduction decreases only slightly from 98% to 92%. This result shows that the forward hedge is still very effective and the correlation effect is the main explanation for the low hedge ratios. The very low hedge ratio for the US Dollar at a ten-year hedge horizon, however, can partly be explained by the increased importance of non-hedgable risks, as the clear drop in the hedging effectiveness shows. In this case, it might pay to look for alternatives to a pure financial hedge with currency forward contracts. This analysis will be done in Chapter 3.

2.3.4 Optimal Hedge Ratios for CARA Utility

Hedge positions that minimize profit variance are determined in Subsection 2.2.2. Variance-minimization has its clear benefits in terms of tractability. Moreover, as firms do not tend to be successful in selective hedging,²⁸ a focus on risk minimization seems appropriate from a practical point of view. However, variance-minimization also has its drawbacks; in particular, it fits into the framework of expected utility maximization only under restrictive additional assumptions. Therefore, as a robustness check, we use the maximization of the expected utility of real profits according to a constant absolute risk aversion (CARA) utility function as an alternative decision criterion. CARA utility

 $^{^{28}\}mathrm{See}$ Adam and Fernando (2006) and Brown, Crabb, and Haushalter (2006).

is often used in finance²⁹ and it is convenient in our setting, wherein negative profits are possible.³⁰ Formally, a CARA utility function is defined as

$$U(W) = -\frac{1}{e^{\alpha \cdot W}},\tag{2.22}$$

where α is the coefficient of absolute risk aversion.³¹ In our robustness check, the following values of the coefficient of absolute risk aversion are considered: {1,2,3,4,5,10,20}. The chosen range for α is in line with empirical findings about the risk aversion of international non-financial firms with respect to exchange rate risk.³²

As before, we follow a maturity matched hedging strategy and real profits for a particular hedge horizon t are given by

$$\tilde{\Pi}_{real,t} = P_0 Q X_0 (1 + \tilde{u}_t) - C_0 + H_t \left(F_{0,t} \frac{1}{(1 + \tilde{\epsilon}_{h,t})} - X_0 \frac{(1 + \tilde{u}_t)}{(1 + \tilde{\epsilon}_{f,t})} \right).$$
(2.23)

Without loss of generality, we set values for the initial price P_0 , the production quantity Q and the exchange rate at time zero X_0 equal to one. The costs C_0 were set equal to 0.5, so that the exporting firm has an initial profit margin of 50%.³³

A first investigation, using the same assumptions as in Section 2.2, shows that the hedge ratios are heavily driven by speculative effects. The reason for a speculative demand for forward contracts lies in the use of the covered interest rate parity relation to determine forward prices according to Equation (2.8). In combination with our econometric model for exchange rate dynamics, this procedure can lead to biased forward prices (both backwardation and contango) and, hence, causes speculative demand. As expected, we generally observe that speculative demand increases with decreasing risk aversion parameters.

²⁹See, for instance, Huang and Litzenberger (1988), p. 25 f, Lapan, Moschini, and Hanson (1991), Briys, Crouhy, and Schlesinger (1993), and Moschini and Lapan (1995).

³⁰Note that a utility function with constant relative risk aversion (CRRA) is not defined for negative profits.

 $^{^{31}}$ See Arrow (1971) and Pratt (1964).

 $^{^{32}}$ See, for example, Pausenberger and Völker (1985) and other references cited there.

³³Changing the margin does not have a strong impact on the hedging decision, as the results for different margins show.

If we use variance-minimization as our decision criterion, speculative demand is excluded by assumption. In order to make our analysis for the CARA utility function comparable to our previous analysis, we try to mitigate incentives to speculate. To achieve this, we use unbiased forward prices, which are calculated via the following equation

$$F_{0,t} = E(\tilde{X}_t) = X_0 \cdot E\left(\frac{(1+\tilde{\epsilon}_{h,t})}{(1+\tilde{\epsilon}_{f,t})}(1+\tilde{u}_t)\right), \qquad (2.24)$$

as the sample averages for all simulated $\tilde{\epsilon}_{h,t}s$, $\tilde{\epsilon}_{f,t}s$, and \tilde{u}_ts .

Optimal hedge ratios from this second investigation are shown in Table 2.8 for the case of the US Dollar.³⁴

α	1 month	6 months	1 year	2 years	5 years	10 years
1	1.16	1.12	1.08	0.99	0.74	0.36
2	1.15	1.10	1.07	0.98	0.74	0.35
3	1.15	1.10	1.06	0.98	0.73	0.33
4	1.15	1.10	1.06	0.98	0.73	0.31
5	1.15	1.09	1.06	0.98	0.72	0.28
10	1.15	1.09	1.05	0.97	0.69	0.21
20	1.15	1.09	1.05	0.96	0.63	0.17
VM	0.97	0.93	0.89	0.83	0.64	0.34

Table 2.8: Hedge ratios that maximize expected CARA utility for different hedge horizons and different levels of risk aversion for the US Dollar. The last row shows the variance-minimizing hedge ratios for the US Dollar.

The results shown in Table 2.8 are not easy to interpret in every detail, but confirm the general findings of the variance-minimization approach. First, the term structure of hedge ratios is also clearly decreasing. Second, hedge ratios are close to one for short horizons, although a weak overhedging is observed. This overhedging might be due to the complicated correlation structures of the different sources of risk that are involved. Third, the hedge ratios for longer hedge horizons (five years or longer) lie substantially below one, reaching values of 36% or lower. Finally, the effects of different levels of risk aversion on hedge ratios are not very strong. Substantial differences occur only for

 $^{^{34}}$ Results for the other two currencies support the general findings for the US Dollar.

very long hedge horizons. Therefore, in conclusion, we can state that the results are robust and support our previous findings based on variance-minimization.

2.4 Conclusion

This chapter analyzes the hedging of exchange rate risk at different hedge horizons. In an initial step, we derive variance-minimizing currency hedge ratios for an exporting firm, taking uncertain revenues, costs, and exchange rates into account. In a second step, the term structure of currency hedge ratios is quantified in an empirical study. Based on a cointegrated VAR model of prices and interest rates in two countries and the exchange rate, we simulate future price paths by means of a bootstrap algorithm. These price paths allow us to quantify hedge ratios for different hedge horizons and the hedging effectiveness.

Our empirical study provides three major results. First, it shows that a substantial underhedging of exchange rate risk for longer hedge horizons can be explained to a large extent by the interplay of prices and exchange rates, i.e., by the existence of natural hedges. Accordingly, although hedge ratios become quite low, hedging effectiveness is still high. This result holds irrespective of our finding that there is no mean reversion towards PPP. Second, it can be important to follow different hedging strategies for different currencies. In fact, the price and exchange rate dynamics captured by our VAR model imply a ten-year hedge ratio for the US Dollar as low as 34%. For the British Pound and the Japanese Yen, the corresponding hedge ratios are still approximately 50%. Third, for short hedge horizons of up to one year differences between currencies are very small and hedge ratios are still close to one, i.e., firms cannot rely on natural hedges for shorter hedge horizons.

The most important driving forces behind our results are the integration and cointegration properties of the risk factors that determine the hedge ratios, since the degree of integration strongly influences how a certain risk increases with the hedge horizon. Thus, our study highlights that decisions on longer-term hedging arrangements deserve a careful analysis of the integration properties of revenues, costs, and exchange rates.

2.5 Appendix



(c) Interest Rates

Figure 2.4: Overview of time series in levels.



(a) log PPI, first difference



(b) log PPI, second difference

Figure 2.5: Overview of time series: Log PPI.



(a) log FX, first difference



(b) log FX, second difference

Figure 2.6: Overview of time series: Log FX.





(b) Interest rates, second difference

Figure 2.7: Overview of time series: Interest rates (monthly).



(a) ppp



(b) ppp, first difference

Figure 2.8: Overview of the absolute purchasing power parity ppp.

=

Dummy	Explanation
Structural	
1982:01	Change from high-inflation era to low-inflation era
1999:03	Change from low-inflation era to high-inflation era
Permanent	
1979:10	Increase of federal fund rate from 11.50% to 13.00%
1980:05	Reduction of federal fund rate from 11.50% to 10.75%
1980:11	Increase of federal fund rate from 13.75% to 18.00%
1981:02	Oil price shock (Second oil price crisis), beginning of Iran-Iraq War
1982:06	Reduction of federal fund rate from 13.00% to 9.50%
1982:10	Reduction of federal fund rate from 10.00% to 9.50%
1986:04	Imported demand-induced inflation due to cost savings
	(lower oil prices, labor costs)
1986:10	Imported demand-induced inflation due to cost savings
	(lower oil prices, labor costs)
1987:04	Increase of federal fund rate from 6.00% to 6.50%
1990:02	German Reunification
1990:08	Gulf War, German Reunification
1991:01	Gulf War, German Reunification
1996:01	Reduction of discount rate from 3.50% to 3.00% in a process of several cuts in interest rates
2001:10	Reduction of European Central Bank (ECB)'s interest rates
	for main refinancing operations from 4.50% to 3.75% ;
	huge interest rate speculations;
	terrorist attacks on September 11, 2001
Transitory	
1980:02	Reduction of federal fund rate from 15.00% to 11.50%
1981:06	Reduction of federal fund rate from 20.00% to 15.50%
1981:11	Reduction of federal fund rate from 15.50% to 12.00%
1986:03	Increase of oil production by early 1986; hence decrease
	of crude oil prices below \$10 per barrel
2005:09	Hurricane Katrina; high increases in commodity prices

Table 2.9: Description of the dummies for the US VECM.

Dummy	Explanation
Structural	
1982:08	Change from high-inflation era to low-inflation era (first step)
1985:04	Change from high-inflation era to low-inflation era (second step)
Permanent	
1975:11	First oil price crisis
1976:10	Increase of Bank of England (BOE)'s base rate from 12.00% to 14.00%
1976:11	Health care tax increase
1977:01	Decrease of BOE's base rate from 14.00% to 13.00%
1977:04	Decrease of BOE's base rate from 9.50% to 9.00%
1977:09	Decrease of BOE's base rate from 8.00% to 7.00%
1979:03	Decrease of BOE's base rate from 13.00% to 12.00%
1979:07	Second oil price shock; increases in value added tax under
	the first Thatcher administration
1979:11	Increase of BOE's base rate from 14.00% to 17.00%
1980:01	Increase of discount rate from 5.00% to 6.00% and lombard rate from 6.00% to 7.00%
1986:04	Imported demand-induced inflation due to cost savings
	(lower oil prices, labor costs)
1986:10	Imported demand-induced inflation due to cost savings
	(lower oil prices, labor costs)
1992:09	Leaving of the UK £of the ERM when it came under
	overwhelming pressure caused by a large-scale selling of UK \pounds
	in the foreign exchange markets.
2001:10	Reduction of ECB's interest rates for main refinancing operations
	from 4.50% to 3.75% ; huge interest rate speculations;
	terrorist attacks on September 11, 2001
Transitory	
1975:10	Increase of BOE's base rate from 10.00% to 11.00%
1980:03	Increase of discount rate from 6.00% to 7.00% and
	lombard rate from 7.00% to 8.50%
1980:07	Decrease of BOE's base rate from 17.00% to 16.00%
1981:01	Sudden increase in the value of the UK's oil reserves coupled
	with the tight monetary policy during $1980/81$ caused a substantial
	appreciation of the sterling exchange rate; UK recession
1982:01	Decrease of discount rate from 7.00% to 6.00% and
	lombard rate from 8.00% to 7.00%

$\underline{\mathbf{UK}}$

Table 2.10: Description of the dummies for the UK VECM.

Dummy	Explanation
Structural	
1982:08	Change from high-inflation era to low-inflation era
2000:04	Change from low-inflation era to high-inflation era
Permanent	
1976:01	First oil price crisis
1979:07	Increase of the basic discount and loan rate from 4.25% to 5.25%
1980:01	Increase of the basic discount and loan rate from 6.25% to 7.25%
1980:03	Increase of discount rate from 6.00% to 7.00% and lombard rate
	from 7.00% to 8.50%
1980:05	Increase of discount rate from 7.00% to 7.50% and lombard rate
	from 8.50% to 9.50%
1981:02	Decrease of the basic discount and loan rate from 7.25% to 6.25%
1981:05	Special behavior of Bundesbank, e.g., Bundesbank granted "special"
	Lombard loans at 3% above the regular lombard rate
1985:01	Begin of deregulation of interest rates on deposits
	(from 1985 on, banks were allowed to pay interest on deposits)
1985:10	Plaza Agreement which depreciated the US Dollar in relation
	to the Japanese Yen and German Deutschmark by intervening
	in currency markets.
1986:10	Imported demand-induced inflation due to cost savings
	(lower oil prices, labor costs)
1989:04	Japanese asset price bubble; increase of the basic discount and
1000 10	Ioan rate from 2.50% to 3.25%
1990:10	Japan Crisis; increase of the basic discount and loan rate
1000 10	from 5.25% to 6.00% ; Gulf War
1998:10	East Asian Financial Crisis
1998:12	East Asian Financial Crisis
2000:01	Pedrotion of ECP's interest rates for main refinancing operations
2001.10	from 4.50% to 2.75% , bugs interest rate speculations
	torrorist attacks on Sontember 11, 2001
	terrorist attacks on September 11, 2001
Transitory	
1980:04	Increase of the basic discount and loan rate from 7.25% to 9.00%
1982:01	Special behavior of Bundesbank
1987:09	Japanese asset price bubble
1989:05	Japanese asset price bubble
1990:02	German Reunification
1997:04	East Asian Financial Crisis
2004:10	Higher commodity prices, mainly oil; supply disorders;
	speculative attacks on the oil price

Table 2.11: Description of the dummies for the JP VECM.

				$\overline{\mathrm{US}}$	_			
β'	ppp_t	$\Delta p_{f,t}$	$\Delta p_{h,t}$	$i_{f,t}^l$	$i_{h,t}^l$	C(1999	9:03)	C(1982:01)
Beta(1)	1.000	-1.229 [-51.798]	2.530 [15.188]	0.312	-1.865	-0.0 [-5.9	02 01]	0.000 [NA]
Beta(2)	-0.976 [-16.087]	1.000 $[NA]$	-1.572 $[-13.540]$	2 -0.519	1.399 [3.824]	0.00 [NA)0 A]	0.001 [6.086]
	=							
	-	α	$\frac{\text{Alpha}(1)}{2}$	Alpha(2	2)			
		Δppp_t	$\begin{array}{c} 0.007 \\ 0.549 \end{array}$	$\begin{array}{c} 0.010 \\ [0.539] \end{array}$				
		$\Delta^2 p_{f,t}$	-1.740 [-8.870]	-2.997	7]			
		$\Delta^2 p_{h,t}$	-1.269 [-12.355]	-1.60 3 [-11.139	3]			
		$\Delta i_{f,t}^l$	-0.004 [-0.454]	-0.003 [-0.235]	3			
		$\Delta i_{h,t}^l$	0.011 [1.697]	0.014 [1.605]				
	=							
П	ppp_t	$\Delta p_{f,t}$	$\Delta p_{h,t}$	$i_{f,t}^l$	$i_{h,t}^l$	C(1999):03)	C(1982:01)
Δppp_t	-0.002	0.001 [0.243]	$\underset{\left[0.337\right]}{0.003}$	-0.003	0.000 [0.075]	-0.0	00 19]	0.000 [0.539]
$\Delta^2 p_{f,t}$	1.186	-0.860	0.310	1.014	-0.948	0.00) 4	-0.003
$\Delta^2 p_{h,t}$	0.295 [6.471]	-0.044 [-1.291]	-0.691 [-11.174]	0.436 [9.934]	0.125 [2.896]	0.00 [12.35) 3 [5]	-0.002 [-11.139]
$\Delta i_{f,t}$	-0.001 [-0.300]	0.002 [0.696]	-0.005 [-1.050]	0.000 [0.068]	$\underset{[0.922]}{0.003}$	0.00 [0.454]	0 4]	-0.000 [-0.235]
$\Delta i_{h,t}$	-0.003 [-1.120]	$\underset{\left[0.497\right]}{0.001}$	$\begin{array}{c} 0.005 \\ [1.260] \end{array}$	-0.004 [-1.492]	-0.000 $[-0.047]$	-0.0 [-1.69]	00 97]	$\begin{array}{c} 0.000 \\ [1.605] \end{array}$
				-				
<u> </u>	$\Gamma_1 \Delta p_1$	$pp_{t-1} \Delta^2$	$p_{f,t-1}$	$\frac{\Delta^2 p_{h,t-1}}{2}$	$\Delta i_{f,t-1}^l$	$\Delta i_{h,t-1}^l$	CON	ISTANT
Δp	$ppp_t = \begin{array}{c} 0.0 \\ 0.0 \end{array}$	$\begin{array}{ccc} 025 & -0 \\ 456 \end{array}$	0.003 -0.847]	-0.001 [-0.174]	-0.156 [-2.147]	$\begin{array}{c} 0.171 \\ ext{[1.614]} \end{array}$		0.000 0.042]
Δ^2	$p_{f,t} = \begin{array}{c} 0.3\\ 0.3\end{array}$	$ \begin{array}{cccccccccccccccccccccccccccccccccccc$.101 2.056]	$\underset{[0.649]}{0.060}$	-0.702 [-0.635]	$\underset{[1.625]}{2.618}$	0	.005 _{9.941]}
Δ^2	$p_{h,t}$ -2.	063 0 .747] [1	.033 1.302]	-0.085 [-1.750]	-0.649 [-1.122]	$1.951 \\ [2.313]$	- ().001 -2.496]
Δi	$i_{f,t}^l$ -0.	075 0 .053] [0	.001 0.263]	$\begin{array}{c} 0.004 \\ 0.935 \end{array}$	$\underset{[6.407]}{\textbf{0.312}}$	-0.066 [-0.928]	 [-	0.000 -1.337]
Δa	$i_{h,t}^l$ -0.	082 0 .998] [0	.000 0.110]	-0.001 [-0.360]	$\underset{[3.568]}{\textbf{0.129}}$	$\underset{[4.613]}{\textbf{0.244}}$		0.000 -0.629]

Note: t-statistics in brackets. Significant test statistics are given in **bold** face.

Table 2.12: Long-run and short-run structure of the VECM model for the US.

$\underline{\mathbf{U}\mathbf{K}}$

β'	pp	pp_t	Δp_f	$_{,t}$ Δp_h	,t	$i_{f,t}^l$	$i_{h,t}^l$	C(198	2:08)	C(1985:0)4)
Beta(1	1) 1.0 [N	$000_{[A]}$	-0.5 9	1.32	2 0 5]	0.429 [1.893]	-0.413	0.0 [3.23	03 84]	0.000 [NA]	
Beta(2	2) -1.6	026 .491]	1.00 [NA]	0 -0.6	9 0 60]	-0.099	-0.236	$5 \qquad \stackrel{\circ}{0.0}_{[N]}$	$\begin{array}{c} 00\\ A \end{array}$	0.002 [3.747]	
						[]	[]				
		=	α	Alpha(1	L)	Alpha(2	2)				
			Δppp_t	0.007 [1.215]		0.004					
			$\Delta^2 p_{f,t}$	-0.344	ŀ	-0.99]	L .]				
			$\Delta^2 p_{h,t}$	-0.71 5 [-11.352]	-0.447 [-6.223]	7				
			$\Delta i_{f,t}^l$	$\underset{\left[0.553\right]}{0.003}$		$\underset{[0.031]}{0.000}$					
		_	$\Delta i_{h,t}^l$	0.004 [0.986]		-0.005 [-1.234]	5				
						,					
Π	pp_{l}	D_t	$\Delta p_{f,t}$	$\Delta p_{h,i}$	Ļ	$i_{f,t}^l$	$i_{h,t}^l$	C(1982)	:08)	C(1985:04	1)
Δppp_t	9 0.00 [0.58) 3 33]	-0.00	$egin{array}{ccc} 0 & 0.007 \ 1 & [1.179] \end{array}$	7	$\begin{array}{c} 0.003 \\ [1.260] \end{array}$	-0.004 [-1.056]	0.00 [1.215	0 5]	$\begin{array}{c} 0.000 \\ [0.614] \end{array}$	
$\Delta^2 p_{f,t}$	0.6	73	-0.78	6 0.23)	-0.049	0.376	-0.00)1	-0.002	
$\Delta^2 p_{h,t}$	-0.2	57 791	-0.01	9 -0.63	6	-0.263	[9.244] 0.401	- 0.0 ()2 52	-0.001	
$\Delta i_{f,t}^l$)3)6]	-0.00	2 0.004	L L	0.001	-0.001	0.00	$\begin{bmatrix} 0 \\ 2 \end{bmatrix}$	0.000	
$\Delta i_{h,t}^l$	0.00)9] 09]	-0.008	8 0.00	9	0.002	[-0.373] -0.000	0.00	0	-0.000	
	[1	[] [[]	[0.115]	[0.000	.1	[1.204]	
	Γ_1	$\overline{\Delta pp}$	p_{t-1}	$\Delta^2 p_{f,t-1}$	Δ^2	$^{2}p_{h,t-1}$	$\Delta i_{f,t-1}^l$	$\Delta i_{h,t-1}^l$	CO	NSTANT	
Δ	ppp_t	0.0)88 532]	-0.002		0.005	0.111 [2.182]	-0.041		0.000	
Δ	$\Delta^2 p_{f,t}$	-0.	104	-0.019	ر 	0.009	0.782	0.608		0.011 [14.124]	
Δ	$\Delta^2 p_{h,t}$	- 1 .'	753 .032]	-0.033	ر 	0.079	1.129 [2.067]	1.114	-	-0.000	
Ĺ	$\Delta i_{f,t}^l$	0.0)77 183]	0.002	0 [0.000	0.214 [4.357]	0.097 [1.357]		0.000 [0.285]	
	$\Delta i_{h,t}^l$	-0. [-3	132 712]	0.007 [2.978]	- [-	0.002 -0.760]	0.050 [1.506]	0.320 [6.603]		0.000 [2.359]	

Note: t-statistics in brackets. Significant test statistics are given in **bold** face.

Table 2.13: Long-run and short-run structure of the VECM model for the UK.

J	Ρ	
•	_	

β	3′	ppp_t	$\Delta p_{f,t}$	$\Delta p_{h,t}$	$i_{f,t}^l$	$i_{h,t}^l$	C(198	2:08)	C(2000:04)
Beta	a(1)	1.000 [NA]	-1.256	0.105 [0.925]	-0.070	-0.027	7 -0.0	01 365]	0.000 [NA]
Beta	a(2)	-0.874 [-10.158	1.000	-0.496 [-6.407]	$\begin{array}{c} 0.012\\ 0.012\\ 0.062\end{array}$	0.325 [1.184]	0.0 [N]	00 A]	0.001 [4.552]
		-	α	Alpha(1)	Alpha(2)			
			Δppp_t	-0.002 [-0.174]	$\begin{array}{c} 0.001 \\ 0.038 \end{array}$				
			$\Delta^2 p_{f,t}$	$\begin{array}{c} 0.081 \\ 0.995 \end{array}$	-0.29 [-2.643	3]			
			$\Delta^2 p_{h,t}$	1.164 $[10.584]$	1.527 $[10.253]$	7			
			$\Delta i_{f,t}^l$	-0.005 [-0.652]	0.008 [0.741]				
			$\Delta i_{h,t}^l$	-0.010 [-1.622]	-0.01 [-2.061]	7]			
П	[ppp_t	$\Delta p_{f,t}$	$\Delta p_{h,t}$	$i_{f,t}^l$	$i_{h,t}^l$	C(1982)	2:08)	C(2000:04)
Δp_{I}	pp_t	-0.003 [-0.510]	$\underset{\left[0.567\right]}{0.003}$	-0.001 [-0.076]	$\begin{array}{c} 0.000 \\ \scriptscriptstyle [0.230] \end{array}$	$\begin{array}{c} 0.000 \\ \left[0.052 ight] \end{array}$	0.00 [0.17]	0 4]	$\begin{array}{c} 0.000 \\ 0.038 \end{array}$
$\Delta^2 p$	$O_{f,t}$	0.337 [9.591]	-0.395 $[-10.134]$	0.154 [3.272]	-0.009 [-2.006]	-0.097 [-2.869]	-0.0	00 95]	-0.000 $[-2.643]$
$\Delta^2 p$	$D_{h,t}$	-0.170 [-3.595]	$\underset{[1.245]}{0.065}$	-0.635 $[-10.052]$	-0.064 $[-10.433]$	$\begin{array}{c} {\bf 0.465} \\ {}_{[10.186]} \end{array}$	-0.0 ([-10.5)2 84]	0.002 [10.253]
Δi	$_{f,t}^l$	-0.012 [-3.556]	$\begin{array}{c} \textbf{0.015} \\ [3.823] \end{array}$	-0.005 [-0.985]	$\begin{array}{c} 0.000 \\ [1.033] \end{array}$	$\underset{[0.828]}{0.003}$	0.00 [0.652	0 2]	$\underset{[0.741]}{0.000}$
Δi	$_{h,t}^l$	$\begin{array}{c} 0.005 \\ [1.898] \end{array}$	-0.005 [-1.581]	0.008 [2.113]	$\underset{[1.460]}{0.001}$	-0.005 [-2.080]	0.00 [1.622	0 2]	-0.000 [-2.061]
=				2	. 0	. 1	. 1		
-	$\frac{\Gamma_1}{\Lambda}$	Δp	$pp_{t-1} \Delta$	$p_{f,t-1}^{2}$	$\frac{\Delta^2 p_{h,t-1}}{0.007}$	$\Delta i_{f,t-1}^l$	$\Delta i_{h,t-1}^l$	COI	NSTANT
	Δp_l	$pp_t = 0.$	001 (.202]	0.000 [0.043]	-0.007 [-1.261]	$[0.027]{0.352]}$	$[0.093]{[0.992]}$		[0.544]
	$\Delta^2 p$	$p_{f,t}$ 0. [2	941 -(.920] [-).187 -4.644]	$\underset{[0.172]}{0.006}$	$\begin{array}{c} 0.215 \\ \scriptscriptstyle [0.444] \end{array}$	$\begin{smallmatrix} 0.451\\ \scriptscriptstyle [0.761] \end{smallmatrix}$	- [0.017 -9.661]
	$\Delta^2 p$	$p_{h,t} = -0$).109 —).252] [-	0.104	-0.065	1.118 [1.718]	1.421 [1.782]	().009 [3.587]
	$\Delta i_{.}^{l}$	$f_{f,t} = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$	049 — .509] [-	0.006	0.008 [2.072]	0.164 [3.390]	0.108 [1.817]	().001 [3.488]
	Δi_{j}^{l}	h,t = 0).027 (1.114]	0.004 1.233]	$\begin{array}{c} 0.000 \\ 0.168 \end{array}$	$\underset{[6.979]}{\textbf{0.257}}$	$\underset{[6.332]}{\textbf{0.285}}$		-0.000 -1.938]

Note: t-statistics in brackets. Significant test statistics are given in **bold** face.

Table 2.14: Long-run and short-run structure of the VECM model for Japan.

Chapter 3

Instruments: Hedging Real Profits with FX, Inflation, and Interest Rate Derivatives

3.1 Introduction

Consider as a starting point an international firm whose profit is exposed only to the nominal exchange rate risk. If there is a forward market for this nominal exchange rate risk, a full hedge can completely eliminate the FX risk, so that the firm no longer faces any risk. Unfortunately, this scenario is not realistic. In addition to exchange rate risk, firms usually bear specific revenue risks such as uncertain demand and price risks; hence, we must account for further risk factors when analyzing a firm's exchange rate risk.

On the one hand, a typical exporting firm is exposed to additional product price risk in foreign currency and uncertain costs in the home currency as explained in Chapter 2. Not long ago, the classical hedging literature dealt with only one type of risk in its models.¹ Later, a few models were developed to investigate more than one type of risk. Benninga, Eldor, and Zilcha (1985) and Kawai and Zilcha (1986) considered

¹See, e.g., Danthine (1978) and Holthausen (1979).

revenue risk, in the form of price risk, in addition to exchange rate risk. More recently, Adam-Müller (1997), Giaccotto, Hedge, and McDermott (2001), and Wong (2003) have discussed the impact of additional revenue risks.²

On the other hand, the domestic price level is, in reality, not stable, and firms are affected by inflation risk in that investors are ultimately interested in consumption when concentrating on real profits.³ Briys and Solnik (1992), Adam-Müller (2000), and Battermann and Broll (2001) based their hedging decision on real wealth instead of nominal wealth, embedding inflation risk in their frameworks.

Combining these two effects, the nominal FX forward intended to reduce the FX risk exhibits additive and multiplicative basis risks, which reduce the hedging efficiency of the FX hedge. In Chapter 2, it has been shown that the hedging efficiency in a similar setting decreases to a level of only 77%.

In this chapter, we investigate hedging strategies to improve the performance of the FX hedge in real terms using additional hedging instruments. Thus, the occurring basis risks should be reduced as much as possible. Since the basis risks arise from the price risk in the revenues and costs as well as from considerations of real wealth, the basis risks originate from price changes in the domestic and foreign country. Therefore, derivatives based on price indices seem to be adequate instruments for reducing the evolving basis risks and will be analyzed in the following,⁴ but there are advantages and disadvantages of this sort of derivative. One perspective is that the underlyings of these contracts correlate strongly with the corresponding risk factors. However, if we look at the market in more detail, we see that the inflation linked contracts exhibit several drawbacks, so that their inclusion in the firm's hedging strategy does not seem to be appropriate. The market for inflation derivatives is relatively small and far away from being liquid, which means that high liquidity risk exists.⁵ Additionally, only contracts

 $^{^{2}}$ In these papers, utility is defined over nominal income.

³See, for instance, Adam-Müller (2000, 2002) for more details on this discussion.

⁴In the inflation derivative market, the most popular products are futures contracts on the price level, Treasury Inflation-Protected Securities (TIPS), and inflation linked swaps. Of course, more specialized inflation derivatives can be identified, especially in the OTC market. For further details, we refer to Barclays Capital (2005). For more details on inflation linked products and their pricing, we recommend the papers of Roll (1996, 2004), Jarrow and Yildrim (2003), Lioui and Poncet (2005), Mercurio (2005), and Hinnerich (2008).

⁵Older papers like those of Briys, Crouhy, and Schlesinger (1993) and Adam-Müller (2000, 2002) still assume that inflation risk is untradable.

on the main price level indices are available. For example, on the EUREX the only price index future is based on the harmonized index of consumer prices, excluding tobacco, in the Euro zone. In our case, we assume that prices move in parallel with production prices, on which only a few contracts are currently traded. Furthermore, only a small choice of maturities is available for these kinds of products, so timing mismatches occur. Although these products display properties advantageous for hedging the basis risks, the liquidity problems can interfere with the hedging strategy dramatically.

Other reasonable hedging instruments are interest rate derivatives. Of course, the relation to the basis risks is not that strong, but there are several reasons for using interest rate derivatives to hedge the inflation-induced basis risks. As the main argument, economic theory describes the relationship between nominal interest rates and inflation rates. The Fisher effect (or the Fisher equation) states that the nominal interest rate is made up of two components: A real required return and an inflation premium equal to the expected amount of $inflation.^6$ If we assume that the real required return is constant⁷ or that the real rates at least exhibit mean-reverting behavior⁸, the nominal interest rates move parallel to expected inflation. The Fisher effect exists for the short-term as well as long-term interest rates, which is supported by the empirical results of Lee, Clark, and Ahn (1998), Berument, Ceylan, and Olgun (2007), and Ang, Bekaert, and Wei (2008). In this context, the empirical studies of Fama (1977) and Söderlind (1998) indicate that interest rates are good predictors of inflation rates.⁹ We can conclude that the interest rates contain useful information about future inflation according to the Fisher effect. Furthermore, the real interest rate parity (RIP) describes a relation between interest rates and inflation, extending the Fisher effect to a multi-country case and stating that the real interest rates (i.e., the difference between the nominal interest rate and inflation) should be equal across countries. The empirical evidence on real interest rate equalization is mixed: While the majority of earlier studies on the RIP find that it is rejected for most country pairings,¹⁰ more recent papers using more adequate econometric methods, such as those

 $^{^{6}}$ See Fisher (1930).

⁷See, e.g., Fama (1977) and Nelson and Schwert (1977).

 $^{^{8}}$ See, for instance, Hamilton (1985).

 $^{^9{\}rm The}$ empirical literature, including the studies of Pelaez (1989) and Crowder and Hoffman (1996), weaken this finding.

¹⁰See, for example, the overview in Hallwood and MacDonald (1999).

of Wu and Fountas (2000) and Berument, Ceylan, and Olgun (2007), support the RIP. Svensson (1993), Söderlind (1997), and Söderlind and Svensson (1997) have suggested that forward interest rates (nominal interest rates agreed upon today for an investment period starting in the future) could serve as an indicator of the future path of inflation. Söderlind and Svensson (1997) have shown that the forward rate theoretically consists of expected future inflation, expected real interest rates, the inflation risk premium, and the forward-term risk premium. The forward rate rule assumes that real interest rates are constant and that the inflation risk premium and forward-term risk premium are small and negligible. Consequently, the relation between the forward interest rate and the expected inflation is dominant in this case. In summary, we can say that there are three economic theories which support a relationship between interest rates and inflation. Moreover, the interest rate derivatives market is a very big and liquid market, which is the main advantage in comparison to the inflation products market.

In the finance literature, alternative instruments for hedging inflation risk can be found, such as stocks¹¹, gold¹², and real estate¹³, but empirical evidence for their usefulness is weak.¹⁴ Thus, these instruments are not considered in the current study.

The aim and contribution of the current study is to investigate how a firm facing product price, cost, and exchange rate risks can improve its exchange rate risk management. In essence, we consider various hedging strategies using additional instruments like inflation and interest rate derivatives, which should offset as much of the basis risks of the FX forward as possible. For this purpose, we determine the hedge ratios and hedging efficiencies for different hedging strategies and different hedge horizons. These results help us to answer the following questions: Can additional interest rate or inflation derivatives improve an FX hedging strategy? Which contracts perform best? Which contracts perform best for a certain hedge horizon? What does the design of an adequate hedging strategy look like? Are there possibilities to simplify the hedging strategy?

 $^{^{11}\}mathrm{See},$ e.g., Reilly, Johnson, and Smith (1970) and Bodie (1976).

 $^{^{12}}$ See, for instance, Bernard and Frecka (1987).

¹³See, for instance, Hoesli, Liu, and Hartzell (1997) and Hoesli, Lizieri, and MacGregor (2008).

¹⁴See, e.g., Ely and Robinson (1997), Hoesli, Liu, and Hartzell (1997), Taylor (1998), and Hess and Lee (1999).

The starting point of our investigation is a simple model of an exporting firm, similar to that of Chapter 2, which we use to derive the variance-minimizing hedge positions in currency forward contracts and additional hedging instruments. Then, we conduct an empirical study using this analysis in order to quantify the hedge ratios and hedge efficiencies of the different hedging strategies for a German firm that exports to the US. This study estimates a VAR model with possible cointegration relationships between price levels, exchange rate, and short-/long-term interest rates. Using the simulated sample paths in the same way as in Chapter 2, hedge ratios and hedge performances are quantified for different hedge horizons and hedging strategies.

The major empirical result reveals that additional instruments can improve the FX hedge performance immensely. For shorter hedge horizons, inflation derivatives are very useful, but for longer hedge horizons, interest rate derivatives based on long-term interest rates perform best. Due to the integration and cointegration properties of the prices, the inflation derivatives become very risky for longer hedge horizons and lead to immense hedging errors since correlation is no longer perfect, so the FX hedging strategy cannot benefit from their use in the case of longer hedge horizons. Here, domestic and foreign long-term interest rate derivatives perform much better, since interest rates are not that risky. This hedging strategy can be simplified by using only one forward on the long-term interest rate spread in addition to the FX forward without a performance reduction. In a nutshell, the choice of the adequate hedging instruments is not as obvious as it seems at first glance, and the FX hedging strategy must be carefully designed.

The remaining part of this chapter is organized as follows: Section 2 introduces the model of an exporting firm which hedges using combinations of different forward contracts. We then derive the variance-minimizing hedge ratios and define possible hedging strategies to improve the FX hedge. In the empirical study of Section 3, (1) the data-set and the study design are presented, (2) the VAR model is specified, and (3) the results of the hedging strategies using inflation or interest rate derivatives are illustrated and discussed. Section 4 presents a summary and a conclusion of the analysis.

3.2 Model Analysis

3.2.1 Model Setup

In this part, we expand the approach of the former chapter by adding inflation and interest rate derivatives to the hedging strategy. As we have discussed before, it is now reasonable to follow the maturity matched hedging strategy. Thus, the foundation for this model is a nominal profit equation which already hedges the exchange rate risk using an FX forward contract and is derived by inserting the representation of Equation (2.8) into Equation (2.5):¹⁵

$$\tilde{\Pi}_{t} = P_{0} Q X_{0} (1 + \tilde{\epsilon}_{h,t}) (1 + \tilde{u}_{t}) - C_{0} (1 + \tilde{\epsilon}_{h,t}) + H_{t}^{FX} \left(F_{0,t}^{FX} - X_{0} \frac{(1 + \tilde{\epsilon}_{h,t})}{(1 + \tilde{\epsilon}_{f,t})} (1 + \tilde{u}_{t}) \right).$$
(3.1)

Since the incorporation of the interest rate derivatives is considered, we need a contract that directly trades the underlying interest rate. That is why we consider some kind of synthetic interest rate forward where the profits are proportional to the difference between the underlying interest rate at contract maturity and the contract rate entered into at contract inception. This type of contract is based on the major properties of the well-known Eurodollar or Euribor futures.¹⁶ For the Eurodollar futures, high trading volumes are observed even for contract maturities of up to 10 years, which correspond to the considered hedge horizons in this study. Since the OTC market for interest rate derivatives is very large, we believe that the applied synthetic products are reasonable. We assume that the contracts are quoted in Euro, so that no additional exchange rate risk is added by using these contracts. Normally, such contracts have a standard size of one million Euros, US Dollars, etc. As underlying short-term interest rates, three-month Treasury Bill Rates are chosen both in the home country and the foreign country, denoted as i_h^s and i_f^s . The underlying long-term interest rates of the contracts are determined as the ten-year government bond yields in both the home country and foreign country, denoted as i_h^l and i_f^l . Finally, we make the simplifying assumption that forward markets of interest rates are unbiased, i.e., the

 $^{^{15}}$ See Section 2.2.1 for details on the derivation of this profit representation.

¹⁶See Bernoth and von Hagen (2004), Hull (2006), p. 137 f, and Bodie, Kane, and Marcus (2007), p. 835 f, for further information.

forward price equals the expected future interest rate.¹⁷ Unbiasedness, which implies that no speculative positions to earn positive expected returns exist, fits well to our criterion of variance-minimization. Whether unbiasedness holds or not is an empirical question, and more recent studies show that it is not easy to statistically reject in the interest rate market. It seems a reasonable starting point for a firm that has no special information about interest rate movements compared to the major market participants.¹⁸ In the context of our model, unbiasedness in the interest rate market

$$F_{0,t}^{h/f,s/l} = E\left(\tilde{i}_{h/f,t}^{s/l}\right).$$

$$(3.2)$$

Thus, the total nominal profit of the considered firm, including all possible hedging transactions, becomes

$$\tilde{\Pi}_{t} = P_{0} Q X_{0} (1 + \tilde{\epsilon}_{h,t}) (1 + \tilde{u}_{t}) - C_{0} (1 + \tilde{\epsilon}_{h,t}) + H_{t}^{FX} \left(F_{0,t}^{FX} - X_{0} \frac{(1 + \tilde{\epsilon}_{h,t})}{(1 + \tilde{\epsilon}_{f,t})} (1 + \tilde{u}_{t}) \right)
+ H_{t}^{h,l} \left(F_{0,t}^{h,l} - \tilde{i}_{h,t}^{l} \right)
+ H_{t}^{f,l} \left(F_{0,t}^{f,l} - \tilde{i}_{f,t}^{l} \right)
+ H_{t}^{h,s} \left(F_{0,t}^{h,s} - \tilde{i}_{h,t}^{s} \right)
+ H_{t}^{f,s} \left(F_{0,t}^{f,s} - \tilde{i}_{f,t}^{s} \right),$$
(3.3)

where $H_t^{FX/h,l/f,l/h,s/f,s}$ is the number of FX and interest rate forwards *sold* in each case. In Subsection 3.2.3, we consider different strategies, which contain some combinations of the interest rate forwards.

According to the discussions in Chapter 2 and Section 3.1, investors are ultimately interested in consumption. Equation (3.4) takes this into account and provides the

¹⁷In contrast, the FX forward market is not assumed to be unbiased for reasons of generality; thus, the FX forward price is determined as the no-arbitrage price via the covered interest rate parity. See Equation (2.8). However, the results in this chapter are robust to this specification using the variance-minimization approach.

¹⁸Cole, Impson, and Reichenstein (1991) and Krueger and Kuttner (1996) have provided evidence that the Treasury Bill Futures Rates are efficient and unbiased, which is also supported by Bernoth and von Hagen (2004) for Euribor futures rates. In contrast, the studies of Cole and Reichenstein (1994) and Krehbiel and Adkins (1994) indicate that the federal funds and Eurodollar futures rates seem to be efficient but contain a positive risk premium since they are upward-biased.

real profit that is the firm's profit in its home currency, measured in prices at time zero:

$$\begin{split} \tilde{\Pi}_{real,t} &= P_0 Q X_0 \left(1 + \tilde{u}_t\right) - C_0 + H_t^{FX} \left(F_{0,t}^{FX} \frac{1}{(1 + \tilde{\epsilon}_{h,t})} - X_0 \frac{(1 + \tilde{u}_t)}{(1 + \tilde{\epsilon}_{f,t})} \right) \\ &+ H_t^{h,l} \left(F_{0,t}^{h,l} \frac{1}{(1 + \tilde{\epsilon}_{h,t})} - \frac{\tilde{i}_{h,t}^l}{(1 + \tilde{\epsilon}_{h,t})} \right) \\ &+ H_t^{f,l} \left(F_{0,t}^{f,l} \frac{1}{(1 + \tilde{\epsilon}_{h,t})} - \frac{\tilde{i}_{f,t}^l}{(1 + \tilde{\epsilon}_{h,t})} \right) \\ &+ H_t^{h,s} \left(F_{0,t}^{h,s} \frac{1}{(1 + \tilde{\epsilon}_{h,t})} - \frac{\tilde{i}_{h,t}^s}{(1 + \tilde{\epsilon}_{h,t})} \right) \\ &+ H_t^{f,s} \left(F_{0,t}^{f,s} \frac{1}{(1 + \tilde{\epsilon}_{h,t})} - \frac{\tilde{i}_{f,t}^s}{(1 + \tilde{\epsilon}_{h,t})} \right) . \end{split}$$

The real profit in Equation (3.4) provides the basis for the firm's hedging decision. As we can see, the risk of the firm's operating profit depends only on the random variable \tilde{u}_t . The risk of the FX forward position, however, depends on both \tilde{u}_t and the development of the price levels $\tilde{\epsilon}_{h,t}$ and $\tilde{\epsilon}_{f,t}$. Due to the additional risk factors in the FX contract, interest rate forwards are included in the hedging strategy to increase the hedging efficiency.

In the second part of the analysis, inflation derivatives are applied to improve the FX hedge. Corresponding to the former discussions, we examine synthetic inflation forwards where the profit is proportional to the difference between the underlying price index at contract maturity and the contract price index level entered into at contract inception. This type of contract is oriented on the Euro inflation futures traded on the EUREX, which has the same properties as the Euribor or Eurodollar futures discussed before. As with the interest rate forward discussed above, we assume that the contracts are quoted in Euro and that the underlying of the contracts is the change in the prices $\tilde{\epsilon}_{h,t}$ and $\tilde{\epsilon}_{f,t}$. Under the assumption of unbiased forward markets, the forward price is as follows:

$$F_{0,t}^{\tilde{\epsilon},h/f} = E\left(1 + \tilde{\epsilon}_{h/f,t}\right). \tag{3.5}$$

The total nominal profit of the considered firm, including all possible inflation hedging transactions, thus becomes

$$\widetilde{\Pi}_{t} = P_{0} Q X_{0} (1 + \widetilde{\epsilon}_{h,t}) (1 + \widetilde{u}_{t}) - C_{0} (1 + \widetilde{\epsilon}_{h,t}) + H_{t}^{FX} \left(F_{0,t}^{FX} - X_{0} \frac{(1 + \widetilde{\epsilon}_{h,t})}{(1 + \widetilde{\epsilon}_{f,t})} (1 + \widetilde{u}_{t}) \right)
+ H_{t}^{\widetilde{\epsilon},h} \left(F_{0,t}^{\widetilde{\epsilon},h} - (1 + \widetilde{\epsilon}_{h,t}) \right)
+ H_{t}^{\widetilde{\epsilon},f} \left(F_{0,t}^{\widetilde{\epsilon},f} - (1 + \widetilde{\epsilon}_{f,t}) \right),$$
(3.6)

where $H_t^{FX/\tilde{\epsilon},h/\tilde{\epsilon},f}$ is the number of FX and inflation forwards *sold* in each case. In Subsection 3.2.3, an overview of hedging strategies which include combinations of the inflation forwards is given.

In real terms, the profit can be written as

$$\widetilde{\Pi}_{real,t} = P_0 Q X_0 (1 + \widetilde{u}_t) - C_0 + H_t^{FX} \left(F_{0,t}^{FX} \frac{1}{(1 + \widetilde{\epsilon}_{h,t})} - X_0 \frac{(1 + \widetilde{u}_t)}{(1 + \widetilde{\epsilon}_{f,t})} \right)
+ H_t^{\widetilde{\epsilon},h} \left(F_{0,t}^{\widetilde{\epsilon},h} \frac{1}{(1 + \widetilde{\epsilon}_{h,t})} - 1 \right)
+ H_t^{\widetilde{\epsilon},f} \left(F_{0,t}^{\widetilde{\epsilon},f} \frac{1}{(1 + \widetilde{\epsilon}_{h,t})} - \frac{(1 + \widetilde{\epsilon}_{f,t})}{(1 + \widetilde{\epsilon}_{h,t})} \right).$$
(3.7)

In this equation, we can see that the inflation forward on the home prices only represents a contract with additive basis risk in real terms, since the underlying has been canceled out. Nevertheless, we expect high improvements in the hedging strategy when using inflation derivatives due to the very strong correlation of the basis risks and the inflation contracts.

3.2.2 Variance-Minimizing Hedges

The firm's hedging problem is choosing the number of forward positions. According to the discussions on the hedging decision criterion in Chapter 2, we again use the variance-minimization approach. For this purpose, we consider the case of Equation (3.4) using all four interest rate derivatives and rewrite real profits for hedge horizons $t = 1, \ldots, T$ including the representations of the interest rate forward prices as

$$\tilde{\Pi}_{real,t} = \tilde{A}_t + H_t^{FX}\tilde{B}_t + H_t^{h,l}\tilde{C}_t + H_t^{f,l}\tilde{D}_t + H_t^{h,s}\tilde{E}_t + H_t^{f,s}\tilde{G}_t$$
(3.8)

with

$$\begin{split} \tilde{A}_t &\equiv P_0 Q X_0 (1+\tilde{u}_t) - C_0, \\ \tilde{B}_t &\equiv X_0 \left(\frac{(1+r_{h,t})}{(1+r_{f,t})} \frac{1}{(1+\tilde{\epsilon}_{h,t})} - \frac{1}{(1+\tilde{\epsilon}_{f,t})} (1+\tilde{u}_t) \right) \\ \tilde{C}_t &\equiv E \left(\tilde{i}_{h,t}^l \right) \frac{1}{(1+\tilde{\epsilon}_{h,t})} - \frac{\tilde{i}_{h,t}^l}{(1+\tilde{\epsilon}_{h,t})}, \\ \tilde{D}_t &\equiv E \left(\tilde{i}_{f,t}^l \right) \frac{1}{(1+\tilde{\epsilon}_{h,t})} - \frac{\tilde{i}_{f,t}^l}{(1+\tilde{\epsilon}_{h,t})}, \\ \tilde{E}_t &\equiv E \left(\tilde{i}_{h,t}^s \right) \frac{1}{(1+\tilde{\epsilon}_{h,t})} - \frac{\tilde{i}_{h,t}^s}{(1+\tilde{\epsilon}_{h,t})}, \quad \text{and} \\ \tilde{G}_t &\equiv E \left(\tilde{i}_{f,t}^s \right) \frac{1}{(1+\tilde{\epsilon}_{h,t})} - \frac{\tilde{i}_{f,t}^s}{(1+\tilde{\epsilon}_{h,t})}. \end{split}$$

The firm's decision problem then becomes for each hedge horizon t

$$\min_{H_t^{FX}, H_t^{h,l}, H_t^{f,l}, H_t^{h,s}, H_t^{f,s}} Var\left[\tilde{\Pi}_{real,t}\right],$$
(3.9)

which is similar to the hedging problem (2.12) in Chapter 2. Variance-minimization derives the necessary first order conditions in the equation system (3.10). Assuming that none of the applied hedging instruments is redundant, optimal forward positions are obtained. In other words, the necessary conditions of the variance-minimizing hedging strategy given in the normal equations (3.10) are sufficient for a unique minimum if the variance-covariance matrix of $\tilde{B}_t, \ldots, \tilde{G}_t$ has full rank.

$$Cov[\tilde{A}_{t}, \tilde{B}_{t}] + H_{t}^{FX} Var[\tilde{B}_{t}] + H_{t}^{h,l} Cov[\tilde{B}_{t}, \tilde{C}_{t}] + H_{t}^{f,l} Cov[\tilde{B}_{t}, \tilde{D}_{t}] + H_{t}^{h,s} Cov[\tilde{B}_{t}, \tilde{E}_{t}] + H_{t}^{f,s} Cov[\tilde{B}_{t}, \tilde{G}_{t}] \stackrel{!}{=} 0 Cov[\tilde{A}_{t}, \tilde{C}_{t}] + H_{t}^{h,l} Var[\tilde{C}_{t}] + H_{t}^{FX} Cov[\tilde{C}_{t}, \tilde{B}_{t}] + H_{t}^{f,l} Cov[\tilde{C}_{t}, \tilde{D}_{t}] + H_{t}^{h,s} Cov[\tilde{C}_{t}, \tilde{E}_{t}] + H_{t}^{f,s} Cov[\tilde{C}_{t}, \tilde{G}_{t}] \stackrel{!}{=} 0 Cov[\tilde{A}_{t}, \tilde{D}_{t}] + H_{t}^{f,l} Var[\tilde{D}_{t}] + H_{t}^{FX} Cov[\tilde{D}_{t}, \tilde{B}_{t}] + H_{t}^{h,l} Cov[\tilde{D}_{t}, \tilde{C}_{t}] + H_{t}^{h,s} Cov[\tilde{D}_{t}, \tilde{E}_{t}] + H_{t}^{f,s} Cov[\tilde{D}_{t}, \tilde{G}_{t}] \stackrel{!}{=} 0$$
(3.10)
$$Cov[\tilde{A}_{t}, \tilde{E}_{t}] + H_{t}^{h,s} Var[\tilde{E}_{t}] + H_{t}^{FX} Cov[\tilde{E}_{t}, \tilde{B}_{t}] + H_{t}^{h,l} Cov[\tilde{E}_{t}, \tilde{C}_{t}] + H_{t}^{f,l} Cov[\tilde{E}_{t}, \tilde{D}_{t}] + H_{t}^{f,s} Cov[\tilde{E}_{t}, \tilde{G}_{t}] \stackrel{!}{=} 0 Cov[\tilde{A}_{t}, \tilde{G}_{t}] + H_{t}^{f,s} Var[\tilde{G}_{t}] + H_{t}^{FX} Cov[\tilde{G}_{t}, \tilde{B}_{t}] + H_{t}^{h,l} Cov[\tilde{G}_{t}, \tilde{C}_{t}] + H_{t}^{f,l} Cov[\tilde{G}_{t}, \tilde{D}_{t}] + H_{t}^{h,s} Cov[\tilde{G}_{t}, \tilde{E}_{t}] \stackrel{!}{=} 0.$$

If the necessary variances and covariances are available, the variance-minimizing hedge positions given in the system (3.10) can simply be calculated numerically. In particular, the optimal hedge positions depend on all covariances between the profit from operations (\tilde{A}_t) and the payoffs of different forward contracts $(\tilde{B}_t, \ldots, \tilde{G}_t)$, all covariances between the payoffs of different forward contracts, and the initial exchange rate X_0 , but they do not depend on the initial cost C_0 . Solving the normal equation system (3.10), the variance-minimizing forward positions H_t^* s are obtained as:¹⁹

$$\begin{pmatrix}
H_{t}^{FX*} \\
H_{t}^{h,l*} \\
H_{t}^{h,l*} \\
H_{t}^{h,s*} \\
H_{t}^{f,s*} \\
H_{t}^{f,s*}
\end{pmatrix} = \begin{pmatrix}
Var[\tilde{B}_{t}] & Cov[\tilde{B}_{t},\tilde{C}_{t}] & Cov[\tilde{B}_{t},\tilde{D}_{t}] & Cov[\tilde{B}_{t},\tilde{E}_{t}] & Cov[\tilde{B}_{t},\tilde{G}_{t}] \\
Cov[\tilde{C}_{t},\tilde{B}_{t}] & Var[\tilde{C}_{t}] & Cov[\tilde{C}_{t},\tilde{D}_{t}] & Cov[\tilde{C}_{t},\tilde{E}_{t}] & Cov[\tilde{C}_{t},\tilde{G}_{t}] \\
Cov[\tilde{D}_{t},\tilde{B}_{t}] & Cov[\tilde{D}_{t},\tilde{C}_{t}] & Var[\tilde{D}_{t}] & Cov[\tilde{D}_{t},\tilde{E}_{t}] & Cov[\tilde{D}_{t},\tilde{G}_{t}] \\
Cov[\tilde{E}_{t},\tilde{B}_{t}] & Cov[\tilde{E}_{t},\tilde{C}_{t}] & Cov[\tilde{E}_{t},\tilde{D}_{t}] & Var[\tilde{E}_{t}] & Cov[\tilde{D}_{t},\tilde{G}_{t}] \\
Cov[\tilde{G}_{t},\tilde{B}_{t}] & Cov[\tilde{G}_{t},\tilde{C}_{t}] & Cov[\tilde{G}_{t},\tilde{D}_{t}] & Var[\tilde{E}_{t}] & Var[\tilde{G}_{t}]
\end{pmatrix}^{-1}$$

$$\begin{pmatrix}
Cov[\tilde{B}_{t},\tilde{A}_{t}] \\
Cov[\tilde{G}_{t},\tilde{A}_{t}] \\
Cov[\tilde{D}_{t},\tilde{A}_{t}] \\
Cov[\tilde{G}_{t},\tilde{A}_{t}] \\
Cov[\tilde{G}_{t},\tilde{A}_{t}] \\
Cov[\tilde{G}_{t},\tilde{A}_{t}] \\
Cov[\tilde{G}_{t},\tilde{A}_{t}]
\end{pmatrix}.$$

$$(3.11)$$

Since the variance-minimizing hedge positions depend on all covariances between the profits from operations and the payoffs of different forward contracts, it is difficult to deduce some intuition for the optimal H_t^* s from this. As discussed in Chapter 2, hedging strategies are examined with respect to hedge ratios which are normalized for easier interpretation and comparison. Here, the variance-minimizing hedge ratios are appropriately defined as the ratios of the H_t^* s and the expected revenues at time t in foreign currency, $P_0 Q E(1 + \tilde{\epsilon}_{f,t})$, so the following representation of the optimal hedge ratios is obtained for hedge horizons $t = 1, \ldots, T$:

$$\begin{pmatrix} HR_t^{FX*} \\ HR_t^{h,l*} \\ HR_t^{f,l*} \\ HR_t^{h,s*} \\ HR_t^{f,s*} \end{pmatrix} = \frac{1}{P_0 Q E(1+\tilde{\epsilon}_{f,t})} \cdot \begin{pmatrix} H_t^{FX*} \\ H_t^{h,l*} \\ H_t^{f,l*} \\ H_t^{f,l*} \\ H_t^{h,s*} \\ H_t^{h,s*} \\ H_t^{f,s*} \end{pmatrix} .$$
(3.12)

The hedge ratios in the case of additional inflation derivatives are obtained in a similar way to those described in Equation (3.12).

 $^{^{19}\}mathrm{For}$ more details on the derivation of the optimal hedge positions, refer to Timm (2002), p. 188 f.

3.2.3 Overview of Hedging Strategies

Equation (3.4) illustrates a hedging problem including the FX forward and all possible interest rate forwards. On the one hand, the current study focuses on the influence of the different interest rate derivatives on the FX hedging in order to identify the best choice of interest rate derivatives for improving the real FX hedge. Therefore, we consider the following strategies, selecting the additional interest rate derivatives with respect to maturity or country:

Abbreviation	Description	Restrictions
no hedge	No hedge	$H_t^{FX} = H_t^{h,l} = H_t^{f,l} = H_t^{h,s} = H_t^{f,s} = 0$
only FX	Only FX forward (f)	$H_t^{h,l} = H_t^{f,l} = H_t^{h,s} = H_t^{f,s} = 0$
long IR	FX f, long-term IR f	$H_t^{h,s} = H_t^{f,s} = 0$
short IR	FX f, short-term IR f	$H_t^{h,l} = H_t^{f,l} = 0$
for IR	FX f, foreign IR f	$H_t^{h,l} = H_t^{h,s} = 0$
home IR	FX f, home IR f	$H_t^{f,l} = H_t^{f,s} = 0$
all IR	FX f, all IR f	none
long spread	FX f, long-term IR spread f	$H_t^{h,s} = H_t^{f,s} = 0, H_t^{h,l} = -H_t^{f,l}$

Table 3.1: Overview of hedging strategies using interest rate derivatives.

The strategy "long spread" differs from the others because it is a simplification of the strategy "long IR" in that it only uses one interest rate contract based on the spread of two long-term interest rates. As a result, the strategy is simplified and, in practice, transaction costs are reduced.

On the other hand, the current study focuses on the influence of the different inflation derivatives on FX hedging. Hence, we take the hedging strategies in Table 3.2 into account, where the additional inflation derivatives are selected with respect to country.

In the following empirical analysis, the hedge ratios and hedging efficiencies will be quantified for different hedge horizons and hedging strategies.

Abbreviation	Description	Restrictions
home PPI	FX f, home PPI f	$H_t^{\tilde{\epsilon},f} = 0$
for PPI	FX f, for PPI f	$H_t^{\tilde{\epsilon},h} = 0$
all PPI	FX f, all PPI f	none

Table 3.2: Overview of hedging strategies using inflation derivatives.

3.3 Empirical Study

3.3.1 Study Design and Data-Set

The hedging strategies in our model depend crucially on the joint distribution of the random variables $\tilde{\epsilon}_{h,t}$, $\tilde{\epsilon}_{f,t}$, and \tilde{u}_t , $t = 1, \ldots, T$, as well as the chosen interest rates of \tilde{i}_h^l , \tilde{i}_f^l , \tilde{i}_h^s , and \tilde{i}_f^s . As in Chapter 2, the econometric model that realistically captures the dynamics of prices, exchange rates, and interest rates for such an analysis is a cointegrated VAR model. Using a specified and estimated VAR model for two countries and the algorithm from Chapter 2, the required moments of the random variables $\tilde{\epsilon}_{h,t}$, $\tilde{\epsilon}_{f,t}$, \tilde{u}_t , \tilde{i}_h^l , \tilde{i}_f^l , \tilde{i}_h^s , and \tilde{i}_f^s , $t = 1, \ldots, T$, are quantified and the hedge ratios and efficiencies of the different hedging strategies are determined according to Equations (3.12).

The estimation of the cointegrated VAR model uses the same data-set as in Subsection 2.3.1 and covers the same period. In addition to the prices, exchange rates, and long-term interest rates from the former chapter, we use short-term interest rates, three-month Treasury Bill Rates from the IMF's International Financial Statistics database (CD ROM, 3/2006).

Figures 2.4 to 2.7 in the Appendix of Chapter 2 and Figures 3.4 and 3.5 in the Appendix of this chapter provide an overview of the time series underlying our analysis. The figures strongly indicate that the series are non-stationary. Since integration and cointegration properties of the different series are very important for hedging strategies with respect to different horizons, they will be carefully considered in the concrete specification of the econometric model.

Furthermore, we use the same data for the risk-free interest rates $r_{h,t}$ and $r_{f,t}$ as in Chapter 2.

3.3.2 Specification of the VAR Model

As in Chapter 2, a p-dimensional cointegrated VAR model with k lags is defined according to Equation (2.18). Since the vector time series Y_t , $t = 1, \ldots, \hat{T}$, is assumed to be I(1) in this type of VAR model, its first difference, ΔY_t , is stationary.

In the econometric model that we apply to characterize the hedge ratios and efficiencies of the different hedging strategies, the vector Y_t consists of seven variables. The first five variables - Δp_h , Δp_f , ppp, \tilde{i}_h^l , and \tilde{i}_f^l - are similar to those in the models of Section 2.3. Moreover, short-term interest rates of the home and the foreign country are added. In summary, the vector Y_t is defined as follows:²⁰

$$Y_{t} = \begin{pmatrix} ppp_{t} \\ \Delta p_{f,t} \\ \Delta p_{h,t} \\ \tilde{i}_{h,t}^{l} \\ \tilde{i}_{f,t}^{l} \\ \tilde{i}_{h,t}^{s} \\ \tilde{i}_{f,t}^{s} \end{pmatrix}.$$

$$(3.13)$$

In order to determine the integration rank of each of the above time series the ADF and KPSS tests are applied. The test results shown in Tables 2.1 and 3.3 indicate that all time series are best described as I(1) processes. Furthermore, a graphical inspection of the series confirms these results, which are in line with findings of similar investigations in the literature.²¹

In the next step of model specification, the lag length of the VAR model has to be chosen. The information criteria of Hannan-Quinn and Schwarz recommend a choice of two lags, as given in Table 3.4. Nevertheless, with a lag length of one some autocorrelation remains in the residuals,²² so we choose two lags.²³

²⁰Centered seasonal dummies are used to capture the seasonal effects of the data because the time series are not seasonally adjusted.

 $^{^{21}\}mathrm{See}$ Juselius and MacDonald (2000, 2004).

 $^{^{22}\}mathrm{Corresponding}$ results of an LM test are not reported here.

²³See also Juselius (2006), p. 72, who stresses that a model with two lags is often the best starting point.

	ADF test (t statistics)	KPSS test
i_h^s	-1.40338	1.365^{***}
i_{US}^s	-1.33698	2.267^{***}

Note: For the ADF tests, *, **, and *** mean that the null hypothesis of non-stationarity is rejected at a confidence level of 90%, 95%, and 99%, respectively. The corresponding critical values are -3.451, -2.870, and -2.571, assuming no linear trend. For the KPSS tests, *, **, and *** mean that the null hypothesis of stationarity is rejected at a confidence level of 90%, 95%, and 99%. The lag truncation parameter is set to 8 according to Kwiatkowski et al. (1992), p. 174, since at this value the test settles down. The critical values are 0.347, 0.463, and 0.739, assuming no linear trend in the data.

Table 3.3: Unit root tests.

information criterion	VAR(1)	VAR(2)	VAR(3)	VAR(4)	VAR(5)
Schwarz	-103.114	-103.390	-102.791	-102.248	-101.640
Hannan-Quinn	-105.435	-106.031	-105.749	-105.526	-105.236

Table 3.4: Determination of the lag length.

The graphs of the differenced variables in the Appendix indicate that the underlying normality assumption is not valid for many of the marginal processes. Because we need to control for possible intervention effects, an unrestricted constant²⁴, a few additive outlier corrections²⁵, innovational dummies²⁶, and level shift dummies²⁷ are included.²⁸

In a next step, the cointegration rank r is determined. Results of the trace test are reported in Table 3.5.²⁹ They indicate that the largest two eigenvalues are significantly different from zero. As in Chapter 2, the significance of the third eigenvalue is a

 $^{^{24}\}mathrm{In}$ this way, a trend in levels, but not in differences, is allowed, which matches the behavior of the underlying processes.

²⁵Additive outliers strongly indicate measurement errors and were removed from the time series of the inflation rates in January 2001, January 2003, and January 2005, for Germany and in January 2003, March 2003, and January 2004 for the US.

²⁶Unrestricted permanent and transitory intervention dummies are used if a residual larger than $|3.81 \sigma_{\xi}|$ can be related to a known intervention.

²⁷The level shift dummies are included in the cointegration space and in first differences outside the cointegration relations. In the model, there are level shift dummies in January, 1982 and March, 1999.

 $^{^{28}\}mathrm{A}$ detailed description of the dummies is available from Table 3.15 in the Appendix.

²⁹Since our models contain level shifts that create shifts in the asymptotic distributions, the critical values of the test statistics were simulated using 1,000 random walks and 10,000 replications.
p-r	r	Eig.Value	Trace	Trace*	Frac95	P-Value	P-Value*
7	0	0.387	453.301	438.260	133.775	0.000	0.000
6	1	0.316	275.690	267.323	103.255	0.000	0.000
5	2	0.188	137.705	133.566	76.274	0.000	0.000
4	3	0.102	62.099	54.344	53.707	0.007	0.043
3	4	0.032	23.061	8.582	34.736	0.445	0.997
2	5	0.019	11.304	NA	18.920	0.373	NA
1	6	0.012	4.230	NA	5.921	0.120	NA

Note: *=trace test statistics and p-values are based on the Bartlett small-sample correction.

Table 3.5: Rank determination tests (trace test).

Rank	ρ_1	ρ_2	ρ_3	$ ho_4$	$ ho_5$	$ ho_6$	ρ_7
r = 1	1	1	1	1	1	1	0.474
r = 2	1	1	1	1	1	0.495	0.385
r = 3	1	1	1	1	0.953	0.413	0.384
r = 4	1	1	1	0.996	0.873	0.380	0.380

Table 3.6: Modulus of the five largest roots of the companion matrix for different cointegration ranks.

borderline case. The trace test supports three or even four cointegration relations. However, an examination of the third cointegration relation and an examination of the number of roots of the companion matrix³⁰ in Table 3.6 do not indicate a cointegration rank of r = 3. If the cointegration rank was three, the companion matrix would have only four roots close to unity. Thus, the cointegration rank is set to two although this case does not seem very plausible a priori. In comparison to the models of Chapter 2, the cointegration rank is unchanged, so the two short-term interest rates are not cointegrated with themselves or with the other time series.

In a final step, several misspecification tests to the estimated cointegrated VAR model were applied checking the assumptions of the I(1) approach. Table 3.7 provides the results of these tests. The multivariate LM test statistics for first and second order $\frac{30}{30}$ See Juselius (2006), p. 50 ff.

Tests for autocorrelation:	
LM(1)	0.298
LM(2)	0.060
Test for Normality	0.000
Tests for ARCH:	
LM(1)	0.002
LM(2)	0.000

Table 3.7: Misspecification tests: p-values of the corresponding test statistics.

residual autocorrelation are not significant at the 5% level, so the important property of no autocorrelation is not rejected. As in Chapter 2, Table 3.7 shows that multivariate normality is clearly violated. In fact, non-normality is a less serious problem for the estimation results since the univariate misspecification tests, which are not reported here, indicate that the rejection of normality results from excess kurtosis and not skewness. Moreover, tests on parameter constancy were conducted and support the constancy of the parameters in the chosen reduced rank VAR models.

After having specified the VECMs and checked all of the assumptions of the I(1) model, we obtain a model of the dynamics of prices, interest rates, and exchange rates. A general look at the model in Table 3.16 shows that it is not only well specified from an econometric point of view, but is also economically reasonable in the sense that the signs of the estimated coefficients are plausible in almost all cases.

3.3.3 Results

The VECM that we specified in the previous section can now be used to quantify the various hedge ratios and corresponding hedging performances for different hedge horizons. The hedging effectiveness of the hedging strategies using additional interest rate forwards is shown in Table 3.8 and Figure 3.1.

Hedge horizon	only FX	long IR	short IR	US IR	GER IR	all IR
1 year	0.974	0.978	0.976	0.977	0.975	0.979
2 years	0.965	0.974	0.968	0.970	0.967	0.975
3 years	0.951	0.967	0.956	0.959	0.954	0.969
4 years	0.934	0.958	0.941	0.945	0.938	0.960
5 years	0.914	0.946	0.923	0.929	0.920	0.949
10 years	0.803	0.860	0.815	0.832	0.806	0.861

Table 3.8: Hedging performances using the Johnson measure with respect to interest rate derivative strategies.



Figure 3.1: Hedging performances using the Johnson measure with respect to the important interest rate derivative strategies.

Hedge horizon	HR_t^{FX*}	Hedge horizon	HR_t^{FX*}	$HR_t^{GER,l*}$	$HR_t^{US,l*}$
1 year	0.89	1 year	0.88	-0.39	0.56
2 years	0.82	2 years	0.82	-0.75	0.84
3 years	0.76	3 years	0.76	-1.04	1.07
4 years	0.70	4 years	0.70	-1.25	1.26
5 years	0.64	5 years	0.64	-1.40	1.40
10 years	0.37	10 years	0.38	-1.45	1.61

(a) only FX

(b) long IR

Hedge horizon	HR_t^{FX*}	$HR_t^{GER,s*}$	$HR_t^{US,s*}$
1 year	0.89	-0.22	0.20
2 years	0.83	-0.40	0.23
3 years	0.77	-0.54	0.28
4 years	0.71	-0.62	0.32
5 years	0.65	-0.66	0.35
10 years	0.38	-0.53	0.47

(c)	short	IR
-----	------------------------	----

Hedge horizon	HR_t^{FX*}	$HR_t^{GER,l*}$	$HR_t^{US,l*}$	$HR_t^{GER,s*}$	$HR_t^{US,s*}$
1 year	0.88	-0.17	0.54	-0.25	0.00
2 years	0.82	-0.42	0.85	-0.37	-0.05
3 years	0.77	-0.64	1.09	-0.46	-0.08
4 years	0.71	-0.80	1.29	-0.50	-0.11
5 years	0.65	-0.93	1.44	-0.53	-0.11
10 years	0.39	-1.12	1.63	-0.38	-0.05

(d) all IR

Table 3.9: Hedge ratios for short forward positions in case of the interest rate derivative strategies.

Table 3.8 provides several interesting results. First, interest rate forwards can improve the FX hedge. Second, the enhancement of the hedging performances clearly increases with hedge horizon. For short horizons, we find only small improvements, but for longer horizons the changes are remarkable for certain strategies. Third, for shorter horizons like one or two years, the hedge performance does not vary significantly with the hedging strategies. For longer horizons, the differences between the strategies become considerable. Fourth, forwards written on long-term interest rates are much more suitable than forwards on short-term interest rates in reducing the basis risks of the FX contract. Fifth, a strategy which includes the interest rate forward of only one country does not work satisfactorily. It can be outperformed by a strategy using forwards on the German and US interest rates. Finally, the strategy using only the domestic and foreign long-term interest rate nearly reaches the levels of efficiency of the strategy involving all four interest rate forwards.

In order to get a better understanding of our results and their different interpretations, we must take a closer look at the main driving forces which lie behind them. Our first interpretation of a substantial hedge improvement is the usage of long-term interest rate contracts, following economic theory, as briefly discussed in Section 3.1. According to the Fisher equation the nominal interest rates can be described by real interest rates and inflation. While short-term interest rates are dominated by real rates, the long-term interest rates depend heavily on inflationary components.³¹ This effect is also caused by the behavior of the real rates since they are quite variable for short maturities but smooth for longer maturities.³² Thus, the long-term interest rates and perform much better here. This is the main argument why the strategy "short IR" does not outperform the strategy "long IR". The usage of short-term interest rate forwards has no impact on the real FX hedge.

The second interpretation deals with the simultaneous coverage of both price risks. As the results in Table 3.8 point out, the single-country strategies "GER IR" and "US IR" do not lead to significant performance improvements, whereas the two-country strategy

³¹See, e.g., Ivanova, Lahiri, and Seitz (2000) and Ang, Bekaert, and Wei (2008).

 $^{^{32}}$ See Ang, Bekaert, and Wei (2008).

"long IR" works best. Of course, it is not surprising that the two additional price risks have to be hedged by the corresponding instruments, but these instruments interact and therefore the hedging performance as the sum of the hedging improvements of the single-country strategies is below the improvement of the "long IR" strategy. The two price risks affect the FX contract differently: The German price risk has an effect in form of additive basis risk and the US price risk has a multiplicative basis risk effect. Since the latter risk can be hedged directly, the hedging of the additive basis risk cannot take effect until the multiplicative basis risk is reduced. Thus, these two basis risks interact and must be hedged simultaneously. In this context, the RIP supports the application of a two-country strategy, since it states that the difference between the nominal interest rate and inflation across countries should be equal. The time series of the inflation differential and the nominal interest rate differential move in parallel and the interest rates and inflation rates, in particular, should be considered simultaneously, so that they can take the designated effect. This aspect is also represented in the hedge ratios of the interest rate derivatives in Tables 3.9(b), 3.9(c), and 3.9(d), in which the hedge ratios of the German and US interest rates contracts are approximately equal. In summary, the interplay of these two effects – the better inflation explanatory power of long-term interest rate contracts and the simultaneous usage of domestic and foreign interest rate contracts – drive the performance of the different hedging strategies, and the most reasonable strategy can be easily identified in this context.

Hedge horizon	only FX	long IR	long spread
1 year	0.974	0.978	0.978
2 years	0.965	0.974	0.974
3 years	0.951	0.967	0.967
4 years	0.934	0.958	0.957
5 years	0.914	0.946	0.946
10 years	0.803	0.860	0.859

Table 3.10: Hedging performances using the Johnson measure with respect to the long spread strategy.

Additionally, we investigate a hedging strategy which uses a long-term interest-rate spread forward to facilitate the entire strategy. The results are illustrated in Tables

Hedge horizon	HR_t^{FX*}	$HR_t^{spread*}$
1 year	0.88	-0.52
2 years	0.82	-0.82
3 years	0.76	-1.07
4 years	0.70	-1.26
5 years	0.64	-1.40
10 years	0.39	-1.57

Table 3.11: Hedge ratios for *short* forward positions in case of the long spread strategy whereas $HR_t^{spread*}$ represents the hedge ratio of the spread forward.

3.10 and 3.11. The idea and explanation behind this strategy are again based on the RIP. Indeed, the results show that the hedge performances are almost identical, and the two-country "long IR" can be replaced by the strategy "long spread" as the best interest rate derivative strategy. Using the long-term interest rate spread forward, we can improve the FX hedge significantly by adding only one contract which covers both the domestic and foreign price risk, so the whole strategy is simplified and transaction costs are reduced.³³ Next, we analyze the usage of inflation forwards which are

Hedge horizon	only FX	GER PPI	US PPI	all PPI
1 year	0.974	0.975	0.988	0.999
2 years	0.965	0.967	0.982	0.998
3 years	0.951	0.953	0.973	0.992
4 years	0.934	0.936	0.959	0.982
5 years	0.914	0.918	0.941	0.964
10 years	0.803	0.803	0.805	0.808

Table 3.12: Hedging performances using the Johnson measure with respect to the inflation derivative strategies.

more strongly related to the revenue and cost risks in the FX hedging strategy. The results for the application of inflation forwards in addition to the FX forward are shown in Tables 3.12 and 3.13 as well as Figure 3.2. Naturally, inflation forwards can improve the FX hedge. In contrast to the interest rate derivatives, the hedge

 $^{^{33}}$ Although we do not consider transaction costs here, we consider this to be a relevant argument.



Figure 3.2: Hedging performances using the Johnson measure with respect to the inflation derivative strategies.

improvements are quite large, reaching approximately a full risk reduction for short horizons, while for very long horizons, the enhancement potential almost disappears. In accordance with the interest rate derivatives the usage of a one-country strategy performs significantly below a strategy hedging both the domestic and foreign price risk, which is revealed in Figure 3.2. Again, the "GER PPI" strategy is not able to deliver any hedge improvements, whereas the "US PPI" leads to a considerable increase in hedge efficiency. The two-country strategy, however, is able to eliminate the whole variance of the real profit for hedge horizons up to three years. The main driver for a substantial hedge improvement is the simultaneous usage of the domestic and foreign inflation forward. The arguments are equal to those from the interest rate derivative discussion above. Due to the much stronger correlation with the risk factors, the hedging efficiencies are significantly higher than the ones achieved by the interest rate forwards for short horizons. Surprisingly, the hedge performance of the inflation strategy decreases significantly with increasing hedge horizons, almost arriving at the hedge efficiency level of the basis FX forward strategy. In fact, for longer hedge horizons, the inflation contracts have no effect on real FX hedging, which is mainly determined by the characteristics of the FX forward and the US (foreign) inflation

Hedge horizon	HR_t^{FX*}	$HR_t^{\tilde{\epsilon},GER*}$	Hedge horizon	HR_t^{FX*}	$HR_t^{\tilde{\epsilon},US*}$
1 year	0.90	-0.17	1 year	0.92	0.50
2 years	0.84	-0.19	2 years	0.89	0.44
3 years	0.77	-0.18	3 years	0.85	0.39
4 years	0.71	-0.17	4 years	0.80	0.33
5 years	0.65	-0.14	5 years	0.74	0.27
10 years	0.38	-0.04	10 years	0.39	0.03

(a) FX f and home PPI f

(b) FX f and foreign PPI f

Hedge horizon	HR_t^{FX*}	$HR_t^{\tilde{\epsilon},GER*}$	$HR_t^{\tilde{\epsilon},US*}$
1 year	1.00	-0.80	0.78
2 years	0.99	-0.75	0.71
3 years	0.96	-0.67	0.62
4 years	0.92	-0.59	0.51
5 years	0.85	-0.48	0.41
10 years	0.41	-0.07	0.04

(c) FX f, home PPI f, and foreign PPI f

Table 3.13: Hedge ratios for *short* forward positions in case of the inflation derivative strategies.

forward in the long-run.³⁴ Even for short hedge horizons, both the FX forward and the US inflation forward face basis risks, but their impact is rather small, since the revenue and cost risks and the correlation between revenue risk $(1/(1 + \tilde{\epsilon}_{f,t}))$ and real exchange rate risk $(1 + \tilde{u}_t)$ are negligible. As we have discussed in Chapter 2, on the one hand, the prices underlying the revenue and cost risks follow I(2) processes, so that these risks increase overproportionally with the hedge horizon.³⁵ On the other hand, the correlation between revenue risk and real exchange rate risk increases with the hedge horizon, reaching values higher than 60%.³⁶ Combining these two effects, these basis

³⁴As discussed before, the German (home) contract alone (single-country strategy "GER PPI") has no impact on the real FX hedge. This contract only develops its risk reduction potential in a simultaneous usage together with a US (foreign) contract.

 $^{^{35}}$ In fact, the relative increase in the variance of the prices is an exponential function, which is illustrated in Figure 2.3(a).

 $^{^{36}}$ Figure 2.2(a) shows these effect.

risks rise dramatically over the hedge horizons. As a result, the dependence between the multiplicative basis risk of the FX forward, which should be hedged by the US inflation forward, and the payoff of the US inflation forward is not perfect anymore. Furthermore, the interplay of the risk factors (I(2) processes) inside the US inflation forward accelerates the overall risk of this contract. Then, the strongly increased total risk of the US inflation contract leads to large hedging errors, which can be seen in the significantly decreasing hedge ratios for the US inflation derivatives in Table 3.13. For ten-year hedge horizons, these hedge ratios do not exceed 4%.

Hedge horizon	only FX	long spread	all PPI	all PPI plus long spread
1 year	0.974	0.978	0.999	0.999
2 years	0.965	0.974	0.998	0.998
3 years	0.951	0.967	0.992	0.992
4 years	0.934	0.957	0.982	0.983
5 years	0.914	0.946	0.964	0.967
10 years	0.803	0.859	0.808	0.860

Table 3.14: Hedging performances using the Johnson measure with respect to the major hedging strategies.



Figure 3.3: Hedging performances using the Johnson measure with respect to the major hedging strategies.

Finally, the results of the overall comparison of the major hedging strategies of the set of hedge instruments are illustrated in Table 3.14 and Figure 3.3. The most important finding is that, for short horizons, the inflation strategy "all PPI" improves the FX hedge substantially and outperforms the interest rate strategies dramatically. In contrast, for hedge horizons longer than six years, the long-term spread forward strategy outperforms the inflation strategy. Furthermore, a strategy which includes a long-term interest-rate spread contract and both inflation derivatives represents the maximum hedging efficiency which is achievable in this set up. In particular for middle-term hedge horizons, a combination of both interest rate and inflation derivatives becomes useful.

These results have important practical implications. A firm which faces revenue risk and cost risk in addition to the exchange rate risk can significantly improve its exchange rate risk management by using additional hedging instruments. To do so, inflation derivatives should be chosen for shorter hedge horizons and interest rate derivatives for very long horizons.

3.4 Conclusion

This chapter includes an analysis of hedging strategies to improve the performance of the FX hedge in real terms using additional hedging instruments. In an initial step, we derive the variance-minimizing hedge ratios of extended FX hedging strategies for an exporting firm, taking uncertain revenues, costs, and exchange rates into account. In a second step, the hedge ratios and hedge efficiencies of the different hedging strategies are quantified empirically. Based on a cointegrated VAR model of prices and interest rates in two countries along with the exchange rate, we simulate future price paths by means of a bootstrap algorithm. These price paths allow us to quantify the performances of the considered hedging strategies for different hedge horizons.

Our empirical study provides three major results. First, it shows that interest rate and inflation derivatives can immensely improve the FX hedge in real terms. The addition of the adequate hedging instruments substantially increases the already high hedging efficiency for every hedge horizon. One main reason for this is the simultaneous usage of contracts which are based on domestic and foreign interest rates or prices.

Unfortunately, hedging performance varies strongly with the choice of the additional hedge instruments, so the choice of these hedging instruments is crucial. As the second major result, we find that, for short hedge horizons, the usage of a domestic and foreign inflation derivative can increase the hedge performance to such an extent that almost all of the total variance of the real profit can be eliminated. This is because the basis risks of the FX forward contracts are caused by domestic and foreign price uncertainty which are strongly correlated with the underlyings of the inflation contracts for short horizons. In contrast, for longer hedge horizons, the inflation products lose almost all of their power to improve the FX hedge due to the integration and cointegration properties of prices. However, interest rate contracts can increase the efficiency of the FX hedge substantially, which is our third main result. Here, the adequate strategy includes, in addition to the FX forward, a long-term interest rate spread forward. In other words, we add only one extra contract to the standard FX hedging strategy. This study shows that an FX hedge, in real terms, deserves a careful analysis of the integration and cointegration properties of the prices, interest rates, and exchange rates to design the optimal hedging strategy.

3.5 Appendix



(c) Second difference

Figure 3.4: Overview of time series: Short-term interest rates (monthly) in Germany.



(a) Level



(b) First difference



(c) Second difference

Figure 3.5: Overview of time series: Short-term interest rates (monthly) in the US.

$\mathbf{U}\mathbf{D}$	U	J	S
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Dummy	Explanation
Structural	
1982:01	Change from high-inflation era to low-inflation era
1999:03	Change from low-inflation era to high-inflation era
Permanent	
1980:05	Reduction of federal fund rate from 11.50% to 10.75%
1980:07	Increase of federal fund rate from 9.50% to 10.00%
1981:02	Oil price shock (second oil price crisis), beginning of Iran-Iraq War
1981:03	Reduction of effective federal fund rate from 15.96% to 14.51%
1981:09	Reduction of effective federal fund rate from 17.52% to 16.96%
1981:10	Reduction of effective federal fund rate from 16.96% to 15.06%
1981:11	Reduction of federal fund rate from 15.50% to 13.00%
1982:03	Reduction of federal fund rate from 15.00% to 13.00%
1982:05	Increase of effective Federal Fund Rate from 8.77% to 9.38%
1982:08	Reduction of federal fund rate from 11.50% to 9.50%
1982:10	Reduction of federal fund rate from 10.00% to 9.50%
1984:11	Reduction of federal fund rate from 10.00% to 9.00%
1986:04	Imported demand-induced inflation due to cost savings
	(lower oil prices, labor costs)
1986:10	Imported demand-induced inflation due to cost savings
	(lower oil prices, labor costs)
1988:08	Increase of discount rate from 3.00% to 3.50%
1990:02	German Reunification
1990:08	Gulf War, German Reunification
1990:10	Gulf War
1991:01	Gulf War, German Reunification
1991:03	Gulf War
1996:01	Reduction of discount rate from 3.5% to 3.0% in a process of
	several cuts in interest rates
2001:09	Increase of federal fund rate from 3.50% to 3.00% ;
	terrorist attacks on September 11, 2001
2001:10	Reduction of ECB's interest rates for main refinancing operations
	from 4.50% to 3.75% ; huge interest rate speculations;
	terrorist attacks on September 11, 2001
Transitory	
1980:02	Increase of federal fund rate from 15.00% to 20.00%
1980:03	Reduction of federal fund rate from 20.00% to 11.50%
1980:11	Reduction of federal fund rate from 18.00% to 16.00%
1981:05	Reduction of federal fund rate from 20.00% to 15.50%
1984:12	Increase of federal fund rate from 8.25% to 9.00%
2005:09	Hurricane Katrina; high increases in commodity prices

Table 3.15: Description of the dummies.

$\underline{\mathbf{US}}$

β'	ppp_t	$\Delta p_{f,t}$	$\Delta p_{h,t}$	$i_{f,t}^l$	$i_{h,t}^l$	$i_{h,t}^s$	i_f^s	t C(19	999:03)	C(1982:01)
Beta(1)	1.000 [NA]	-0.933 [-44.221]	2.286 [15.553]	0.810	-1.69	3 -0.22	20 -0.2 37 [-0.5]	22 -0	.002 5.218]	0.000 [NA]
Beta(2)	-1.115 [-16.915]	1.000 [NA]	-1.820 [-14.484]	-0.93	$\begin{array}{ccc} 4 & 1.357 \\ & 1.784 \end{array}$	0.32	$\begin{array}{ccc} 1 & 0.20 \\ 1 & 0.62 \end{array}$	$ \begin{array}{ccc} 09 & 0.\\ 00 & 12 \end{array} $	$\begin{array}{c} 000\\ NA \end{array}$	0.001 [5.235]
			<u> </u>	[1.000					,	
		α	Alpha	(1) Alp	ha(2)					
		Δppp	$t = \begin{array}{c} 0.001 \\ 0.235 \end{array}$	$\begin{bmatrix} 1 & -0 \\ -0 & [-0] \end{bmatrix}$).007).910]					
		$\Delta^2 p_f$	t 1.08 [14.64]	4 0. [1.	213 .809]					
		$\Delta^2 p_h$	t 0.23 [5.525	$\begin{bmatrix} 0 & -0. \\ 0 & [-1] \end{bmatrix}$. 701 0.580]					
		$\Delta i_{f,t}^l$	-0.00	$\begin{array}{ccc} 0.\\ 0.\\ 0.\\ 0.\\ 0. \end{array}$	002 .373]					
		$\Delta i_{h,i}^l$	-0.00)2 0.	010 .589]					
		$\Delta i^s_{h,i}$	-0.00	$\begin{array}{ccc} 2 \\ 3 \\ 3 \\ 3 \\ 1 \end{array} \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix}$	008					
		$\Delta i_{f,t}^s$	-0.00	$\begin{array}{c} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{array}$	010					
			[-1.25	2] [1.						
Π	ppp_t	$\Delta p_{f,t}$	$\Delta p_{h,t}$	i ^l _{f t}	$i_{h,t}^l$	i_{ht}^s	<i>i</i> ^s _{f t}	C(19	99:03)	C(1982:01)
Δppp_t	-0.000	0.000	-0.007	0.000	0.005	-0.001	1 0.000	0.0	000 734]	-0.000
$\Delta^2 p_{f,t}$	1.123	-0.924	0.355	1.001	-0.291	-0.475	5 -0.13	3 0.0	004 635]	-0.003
$\Delta^2 p_{h,t}$	0.104	-0.047	-0.671	0.122	0.485	-0.116	5 0.02	4 0.0	000 002	-0.001
$\Delta i_{f,t}^l$	-0.001	0.001	0.002	-0.001	-0.001	0.001	0.000	-0	.000	0.000
$\Delta i_{h,t}^l$	[-0.000]	-0.000	0.010	[-0.408] -0.001	-0.007	0.001	-0.00	0 -0.	000	0.000
$\Delta i_{h,t}^s$	[-0.148] -0.002	0.001	0.008	[-0.330] -0.002	-0.006	0.002	-0.00	$[-2]{8} = [-2]{00}{-0}$.000	0.000
$\Delta i^s_{\ c}$,	[-0.565] -0.003	$\begin{array}{c} \left[0.369\right]\\ 0.002\end{array}$	$\begin{array}{c} \left[1.694 \right] \\ 0.009 \end{array}$	[-0.699] -0.003	[-1.663] -0.007	[1.230] 0.002	[-0.52 - 0.00]	1] $[-1]$ 00 -0.	.952] 000	$\begin{array}{c} \left[1.721\right]\\ 0.000\end{array}$
<i>J,t</i>	[-0.712]	[0.511]	[1.688]	[-0.849]	[-1.654]	[1.385]	[-0.41	8] [-2	.080]	[1.866]
	<u></u>	$\Lambda^2 m$	Λ^2 m	Δ	il A	il	Λ_{is}	A :s	Const	tent
$\frac{1}{\Delta ppp_t}$	-0.001	$\frac{1}{1}$ $\frac{\Delta p_{f,}}{-0.0}$	$\frac{t-1}{03}$ $\frac{\Delta p}{0.0}$	$\frac{f,t-1}{002}$ –	$\frac{t_{f,t-1}}{0.144}$	$\frac{u_{h,t-1}}{0.101}$	$\frac{\Delta i_{h,t-1}}{-0.004}$	$\frac{\Delta \iota_{f,t-1}}{0.020}$	-0.0	$\overline{)00}$
$\Delta^2 p_{ff}$	[-0.015] 0.656] [-0.9 0.1 4	$[0.3]{10}$	^{347]} [-)23 —	-1.649] 0.492	[0.802] 1.083	[-0.046] 0.826	$\begin{array}{c} \left[0.405\right] \\ 0.803 \end{array}$	[-0.4 0.00	17] 0 4
$-P_{J,l}$ $\Lambda^2 n_{f,l}$	[0.809] -2 125	[2.98	[0] [0.2	243] [-	-0.370]	[0.568] 1 060	[0.610] 1 267	[1.091]	[9.08]	32] 01
		[1.47]	[-2] [-2] [-2] [-2] [-2] [-2] [-2] [-2]	120] [-	-0.453]	[0.997]	[1.664]	[0.565]		525]
$\Delta i_{f,t}$	-0.069 [-1.746]) [1.08	$ \begin{array}{ccc} 7 \\ 7 \\ \end{array} $ $ \begin{array}{c} -0. \\ \hline \end{array} $	175] [4	4.580] [·	-0.000 -0.603]	-0.013 [-0.189]	-0.055 [-1.541]		22]
$\Delta i_{h,t}^{\iota}$	-0.076 [-2.884]	b 0.00] [0.72	$\begin{array}{ccc} 01 & -0.\\ 0] & [-1] \end{array}$	005 (715] [).051 (1.171]	J.317 [5.099]	-0.085 [-1.917]	0.048 [2.007]		DU 30]
$\Delta i^s_{h,t}$	-0.095 [-2.916]	$\begin{bmatrix} -0.0 \\ -0.7 \end{bmatrix}$	$ \begin{array}{ccc} 01 & -0.\\ 38] & [-0. \end{array} $	003 – 904] [-	0.018 (-0.344]).428 [5.567]	$\underset{[1.151]}{0.063}$	$\underset{[1.599]}{0.048}$	0.00	00 33]
$\Delta i^s_{f,t}$	-0.035 [-0.938]	5 -0.0	$\begin{array}{ccc} 00 & -0.\\ 33 \end{array} & [-0.]{}$	002 (512] [0.067 1.092]	0.065 [0.738]	-0.052 [-0.829]	$0.353 \\ [10.421]$	0.00 [2.01	DO 10]

Note: t-statistics in brackets. Significant test statistics are given in **bold** face.

Table 3.16: Long-run and short-run structure of the VECM model for the US.

Chapter 4

Country Effects: The Currency Risk of International Relocation of Production – The Case of Poland

4.1 Introduction

International relocation of production (or offshoring) is an important issue in the corporate strategy of a multinational enterprise. Relocation of activities from one country to another has become an essential means to improve competitiveness of transnational firms within a globalized network economy. There are several empirical studies to show that many firms have shifted or are going to shift production facilities to foreign countries.¹ Dachs et al. (2006), for example, find that, for a large sample of European firms, one quarter to one half of manufacturing companies in Western European countries perform offshoring of production activities in 2002 or 2003, whereas offshoring is a rather uncommon strategy for Central Eastern European (CEE) countries. These results are supported by country-specific studies such as those by DIHK (2003) for Germany, and industry-specific studies like Kinkel and Lay (2004),

¹Although there is abundant theoretical literature on the firm's location decision, the focus on the firm's relocation is limited in theory.

who analyze manufacturing firms in Germany, as well as van Gorp, Jagersma, and Ike'e (2006), who investigate service firms in the Netherlands. Recently, even small and medium-sized enterprises open up new markets abroad by offshoring parts of their production to foreign countries, as discussed by Bassen, Behnam, and Gilbert (2001) and DIHK (2003), whereas in the past predominantly large multinationals have established production facilities abroad, as shown by Henzler (1992). Thus, the relocation of production is relevant for the majority of firms today.

Arguments for offshoring concentrate on a few major aspects as suggested by survey studies like those of DIHK (2003), Kinkel and Lay (2004), and Kinkel and Maloca (2008). One important reason for offshoring, mentioned by most of the firms, is to benefit from lower production costs in the target country. Major components of these costs are labor costs, which vary enormously among European Union member countries. On the one hand, there are Western European countries like Denmark, with average labor costs of 35 Euros per hour, while there are Eastern European countries with labor costs as low as 6.70 Euros in Poland or 2.10 Euros in Bulgaria in 2007. In comparison of European countries, Germany ranks in position seven, with 29.10 Euros per hour labor costs.² According to the study by Gardiner and Theobald (2008), construction cost differences are also part of cost considerations for firms. Lower construction costs are able to reduce installation costs, especially in the first stage of the offshoring process. Furthermore, the host government often provides incentives, such as low taxes and subsidies, which can make the production relocation more attractive. Many CEE countries raise only low taxes in comparison to Western European countries and have announced that they intend to keep these taxes at low levels. For example, the Polish corporate income tax rate yielded 19% in 2007, whereas Germany had one of the world's highest corporate tax burdens, with approximately 39% levied, on average, in $2007.^3$ When firms decide to enter backward regions of the European Union, they may also apply for investment grants from structural funds, which are described by Sleuwaegen, Pennings, and De Voldere (1999). Operational hedging motives provide an additional reason for production relocation, which have been empirically confirmed by Allayannis, Ihrig, and Weston (2001), Pantzalis, Simkins, and Laux (2001), and

 $^{^2\}mathrm{More}$ details can be found in Statistisches Bundesamt (2008).

 $^{^{3}}$ See Kesti (2007).

DIHK (2003) for the case of Germany.⁴ Consider a manufacturing firm with production and sales operations in foreign countries that is exposed to demand and exchange rate risks. A suitable operational hedging policy would be to shift production to a country wherein high sales revenues in the foreign currency are expected, so that the effect of unexpected changes in exchange rates and foreign demand conditions on the domestic currency value of sales revenues is hedged by similar changes in the domestic currency value of foreign production costs.⁵ Additional but rather minor reasons for offshoring are the improving infrastructure in the low-cost countries and the significant reduction in trade barriers in these regions.⁶

Regardless of all the advantages listed above, problems can occur when shifting production to foreign countries. Studies such as those of Bates (2005) and Kinkel and Maloca (2008), indicate that there are firms that have offshored production facilities to foreign countries and have afterward moved production back to the home country.⁷ Depending on the country, between 15% and 50% of offshorers backshored their production in 2002 and 2003. In Germany, approximately one third of the emigrated firms returned. Survey studies like those of Kinkel, Lay, and Maloca (2004), Kinkel, Dachs, and Ebersberger (2007), and Kinkel and Maloca (2008), provide several explanations for this observation. One important reason is quality problems that are caused by required standards that cannot be fulfilled, which results in significantly increased quality control costs and costs of supporting the foreign production facilities. Furthermore, flexibility and supply availability losses lead to supply problems and additional storage costs. In the present study, the cost aspect is discussed as an advantage of offshoring, however, firms consider costs as an important factor for break-ups abroad as well. The term "costs" covers costs for production factors, as well as expenses required for coordination and communication, which can be immense, especially in the first stage of relocation. Prior to relocation, these costs are often underestimated and the real amounts do not become clear until relocation commences.

⁴This argument is already discussed in Chapter 2.

⁵Further details on operational hedging can be found in Chowdhry and Howe (1999) and Boyabatli and Toktay (2004).

⁶The survey studies mention other reasons for production shifting, such as to overcome capacity bottlenecks, to open new markets, movements to the vicinity of key customers, and flexibility in the ability to supply.

⁷Schulte (2002) investigates the backshoring phenomenon theoretically.

Moreover, the fact that most costs must be paid in foreign currency, in cases in which the foreign country uses a different currency than the company's home currency, further accelerates the cost risk for firms that practice offshoring.⁸ The possible negative impact of exchange rate risks can be illustrated with the example of the relocation of Volkswagen's Fox production to Brazil. Unfavorable developments of the Brazilian Real burdened the company's operating profit by more than 200 million Euros.⁹ This discussion shows that currency risk is, for the most part, ignored or underestimated in the relocation process.

Thus, the aim and contribution of this chapter is to investigate exchange rate risks of production shifting to foreign countries.¹⁰ To do so, special cases of a firm, which are based on specific production strategies, are considered that determine the corresponding term structures of currency risk so that the firm is able to estimate its currency risk for a certain case and time horizon. This information helps firms to decide whether or not to relocate and, in case of relocation, what amount of currency risk the firm will face and how to adjust their corporate strategy accordingly. By doing so, huge losses, such as those Volkswagen incurred in Brazil, can be avoided and no cost intensive backshoring has to be executed. Hence, the following research questions are addressed: What risks does offshoring create? How great are these risks? To what extent do these risks influence production costs measured in home currency? How much can these risks be reduced by an adequate hedging strategy? What level of efficiency can hedging achieve?

The starting point of our investigation is a simple model that is similar to that offered in Chapters 2 and 3. The theoretical model considers a firm in three different cases that arise from certain production strategies. The firm sells its products in the domestic market, but it produces either in the home country or after relocation of production in a foreign country. Additionally, in one case, an FX hedge is applied. As in Chapters 2 and 3, we perform an empirical study to quantify the currency risk for the different cases considering a German firm. The foreign country for the cases of relocation

 $^{^{8}{\}rm The}$ aspect of currency risk is discussed, for instance, in the study of Fuß and Kausch-Becken von Schmeling (2004).

 $^{{}^{9}}See F.A.Z. (2005).$

¹⁰It is important to note that this approach is the opposite of operational hedging, since production is relocated due to cost savings, tax advantages, etc., but not for reasons of matching costs and revenues in the foreign currency.

of production is Poland.¹¹ This study again specifies a VAR model with possible cointegration relations between prices and the exchange rate.¹² By means of simulated sample paths from this model generated by a bootstrap algorithm, we quantify the currency risk of different cases over various time horizons.

The results indicate that a firm which has relocated its production to a foreign country faces a large currency risk that depends heavily on the time horizon. Therefore, a firm with production facilities in foreign countries should not only examine absolute cost reductions in the foreign currency, but should also take care to note the currency risk and its estimation. Furthermore, a hedging strategy that uses an FX forward decreases the currency risk substantially, but a sizeable amount of currency risk remains due to high basis risks, which are typically untradable.

This chapter is organized as follows: Section 2 introduces the model of a firm that sells its products in the domestic market, in which production relocation is described in three different cases. Section 3 contains the empirical study. First, the data-set, including a discussion of Polish monetary policy, is introduced and the study design is briefly explained. Second, we discuss the specification of the VAR model and report cointegration results. Finally, currency risk is quantified for the different cases and time horizons and discussed in detail. Section 4 completes the chapter with a summary and a conclusion.

4.2 Model Analysis

This chapter addresses currency risks of production in a foreign country; a firm selling its products in the home market and producing either in the home market or in a foreign market after a shift in production, is considered.¹³ In this section, additional

¹¹Poland is chosen as one CEE country. It is a direct neighbor of Germany and many production relocations from Germany are directed there, as Kinkel and Maloca (2008) show. Although Poland is a member of the European Union since May 2004 and the Economic and Monetary Union (EMU) of the European Union, it has not completed the third stage of the EMU and therefore still uses its Polish Zloty. The National Bank of Poland and Polish politicians expect to introduce the Euro not before 2012. See Vetter (2007) for details on this argument.

¹²Interest rates are not considered here, since the information content of the Polish three-month Treasury Rate is poor as Figure 4.12 indicates.

¹³Although the examined firm differs from the exporting firm of Chapter 2, the main results of Chapter 2 can be applied in this part, since the general structure of the models is similar.

risks that are caused by offshoring will be addressed. Equivalent to the former chapters, we follow the maturity matched approach. It is assumed that we are currently at time zero and the firm has already decided on the output quantity Q. Goods are sold in the domestic market at time t. The product price \tilde{P}_t is denominated in the home currency and the product price at time t is

$$\tilde{P}_t = P_0 \left(1 + \tilde{\epsilon}_{h,t} \right) \quad \text{for } t = 1, \dots, T.$$

$$(4.1)$$

Because investors are ultimately interested in consumption, as already discussed, we consider real profits as the relevant figure of the firm in the same manner as in the models produced in Chapters 2 and 3. In this study, we want to highlight the effects of currency risks of production shifting, so we investigate three different cases that are based on certain production strategies: (1) The firm produces and sells goods in the home country ("HOME"); (2) the firm has relocated its production and, therefore, produces in a foreign country, but sells its goods in the home country ("FOR"); and (3) the firm is similar to the "FOR" case; additionally, it hedges FX risk using an FX forward contract ("FOR+H").

"HOME" Case

"HOME" represents the base case of the firm. Here, the firm produces its goods in the home market and, therefore, costs appear in the home currency in form of

$$\tilde{C}_t^{HOME} = C_0^{HOME} \left(1 + \tilde{\epsilon}_{h,t} \right) \quad \text{for} \ t = 1, \dots, T.$$
(4.2)

Within this case, the firm generates the following profit for t = 1, ..., T:

$$\tilde{\Pi}_t^{HOME} = \tilde{P}_t Q - \tilde{C}_t^{HOME} = P_0 \left(1 + \tilde{\epsilon}_{h,t}\right) Q - C_0^{HOME} \left(1 + \tilde{\epsilon}_{h,t}\right).$$
(4.3)

In the next step, real profit can be reached for t = 1, ..., T as

$$\tilde{\Pi}_{real,t}^{HOME} = \frac{\tilde{\Pi}_t^{HOME}}{(1+\tilde{\epsilon}_{h,t})} = P_0 Q - C_0^{HOME}.$$
(4.4)

In Equation (4.4), all uncertain elements are canceled out and, therefore, the firm's real profit is certain and independent of the time horizon t. The firm, indeed, faces no

currency or revenue risk in the "HOME" case, so the real profit is certain and identical for each time horizon t, however, no advantages of lower costs in foreign markets are exploited.

"FOR" Case

In the "FOR" case, the firm has relocated its production to a foreign country. Hence, the production costs \tilde{C}_t^{FOR} are incurred in the foreign currency as

$$\tilde{C}_t^{FOR} = C_0^{FOR} \left(1 + \tilde{\epsilon}_{f,t} \right) \quad \text{for} \ t = 1, \dots, T,$$

$$(4.5)$$

and, therefore, the firm now faces currency risk. The firm's nominal profit for t = 1, ..., T is derived as

$$\tilde{\Pi}_t^{FOR} = \tilde{P}_t Q - \tilde{C}_t^{FOR} \tilde{X}_t = P_0 \left(1 + \tilde{\epsilon}_{h,t}\right) Q - C_0^{FOR} X_0 \left(1 + \tilde{\epsilon}_{h,t}\right) \left(1 + \tilde{u}_t\right), \qquad (4.6)$$

where \tilde{X}_t represents the uncertain future exchange rate at $t = 1, \ldots, T$ as defined in Equation (2.4). Thus, real profit can be expressed for each horizon $t = 1, \ldots, T$ as

$$\tilde{\Pi}_{real,t}^{FOR} = \frac{\tilde{\Pi}_t^{FOR}}{1 + \tilde{\epsilon}_{h,t}} = P_0 Q - C_0^{FOR} X_0 (1 + \tilde{u}_t).$$

$$(4.7)$$

Relocation of production to a foreign country causes currency risks in the way that the uncertain relative exchange rate changes \tilde{u}_t are included in the term of the production costs. Although the firm expects a higher or lower cost reduction in the foreign market, additional currency risk is introduced in the "FOR" case.

"FOR+H" Case

A firm that has shifted its production to a foreign market as in the "FOR" case is the starting point of the "FOR+H" case. Costs are again defined according to Equation (4.5). Since production relocation has created currency risks, the firm uses FX forward contracts to hedge its currency risk, unlike in the "FOR" case, so its nominal profits are written as

$$\tilde{\Pi}_t^{FOR+H} = \tilde{P}_t Q - \tilde{C}_t^{FOR} \tilde{X}_t + H_t \left(\tilde{X}_t - F_{0,t} \right), \quad t = 1, \dots, T,$$

$$(4.8)$$

where $F_{0,t}$ denotes the price of the currency forward contract at time 0, which is defined according to Equation (2.8). Substitution of Equations (2.4) and (2.8) into Equation (4.8) and adjusting this equation to real profits lead to the following representation for a time horizon t = 1, ..., T:

$$\begin{split} \tilde{\Pi}_{real,t}^{FOR+H} &= P_0 Q - C_0^{FOR} X_0 (1+\tilde{u}_t) + H_t \left(X_0 (1+\tilde{u}_t) \frac{1}{(1+\tilde{\epsilon}_{f,t})} - F_{0,t} \frac{1}{(1+\tilde{\epsilon}_{h,t})} \right) \\ &= P_0 Q - C_0^{FOR} X_0 (1+\tilde{u}_t) + H_t \left(X_0 \frac{(1+\tilde{u}_t)}{(1+\tilde{\epsilon}_{f,t})} - \frac{X_0 (1+r_{h,t})}{(1+r_{f,t})(1+\tilde{\epsilon}_{h,t})} \right) (4.9) \end{split}$$

Equation (4.9) shows that the risk to the firm's real operating profit depends only on random relative exchange rate changes \tilde{u}_t . However, the risk of the forward position depends on both relative exchange rate changes and development of the price levels in the home country and the foreign country. This situation is similar to that of the exporting firm from Chapter 2, in the maturity matched approach. The only difference exists in the shift of the exchange rate risk from income to costs. As a consequence, the optimal hedging position H_t^* for horizons $t = 1, \ldots, T$ can be derived in the same way as in Equation (2.16):¹⁴

$$H_t^* = \frac{Cov \left[C_0^{FOR} \ X_0 \left(1 + \tilde{u}_t \right), \ X_0 \frac{(1 + \tilde{u}_t)}{(1 + \tilde{\epsilon}_{f,t})} - X_0 \frac{(1 + r_{h,t})}{(1 + r_{f,t})(1 + \tilde{\epsilon}_{h,t})} \right]}{Var \left[X_0 \frac{(1 + \tilde{u}_t)}{(1 + \tilde{\epsilon}_{f,t})} - X_0 \frac{(1 + r_{h,t})}{(1 + r_{f,t})(1 + \tilde{\epsilon}_{h,t})} \right]}.$$
 (4.10)

Within our model, the hedge ratio is defined as the ratio of H_t^* and the expected costs at time t in foreign currency, $C_0^{FOR} \cdot E(1 + \tilde{\epsilon}_{f,t})$, so the optimal hedge ratios become for time horizons $t = 1, \ldots, T$

$$HR_{t}^{*} = \frac{Cov\left[(1+\tilde{u}_{t}), \frac{(1+\tilde{u}_{t})}{(1+\tilde{\epsilon}_{f,t})} - \frac{(1+r_{h,t})}{(1+r_{f,t})(1+\tilde{\epsilon}_{h,t})}\right]}{E(1+\tilde{\epsilon}_{f,t})Var\left[\frac{(1+\tilde{u}_{t})}{(1+\tilde{\epsilon}_{f,t})} - \frac{(1+r_{h,t})}{(1+r_{f,t})(1+\tilde{\epsilon}_{h,t})}\right]}.$$
(4.11)

In the following, we quantify the total risk of the different cases using the first and second moments of uncertain real profits and discuss the results and their impact on corporate strategy. For simplicity, we concentrate on costs when considering first moments, since income is certain in real terms, so we forgo the problem of profit margin determination.

¹⁴The only difference lies in the sign of the hedging position.

4.3 Empirical Study

4.3.1 Exchange Rate Regimes and Inflation Targeting in Poland

In this subsection, we describe the developments of monetary policy in the transition economy Poland with a strong emphasis on exchange rate policy, which has great impact on both the understanding of currency risk in Poland and the considered time series that is elementary for the correct specification of the econometric model in Subsection 4.3.3.¹⁵ A general overview of the exchange rate regimes in Poland and the corresponding details are shown in the Tables 4.1, 4.2, and 4.4. With the fall of the communist regime, the Polish economy suffers a great economic crisis in the summer of 1989. Inflation, which is considered in terms of the Consumer Price Index (CPI) in this subsection, peaked at 54.8%, the government deficit reached almost 8% of the country's Gross Domestic Product (GDP) and both loss-making Polish firms and the government deficit were financed by the rapid expansion of money and credit. Therefore, on January, 1, 1990, radical stabilization reforms, commonly called the "Balcerowicz plan" or the "Big Bang", were launched and Poland entered a transmission period. One major component of the plan aiming at monetary stability was the fixed rate regime, which set the unified rate for foreign exchange at 9,500 Zloty against the dollar after a 31.6% devaluation in support of a single nominal anchor on January, 1, 1990. However, the fixed rate regime did not last long, because inflation accelerated instead of output growth. Therefore, Poland moved to a crawling peg system in October 1991. In this process of transmission, the preannounced crawl rate was gradually lowered and in May 1995 transformed into a crawling band regime with a +/-7% widened band.¹⁶ The success of the economy's stabilization and the obvious shortcomings of the pegged exchange rate regime caused this new direction in monetary policy to float the Polish Zloty. In fact, the exchange rate regime was identified to be, de facto at least, managed floating since 1993, according to Table 4.1 and the studies by Reinhart

¹⁵This subsection is based on the quarterly inflation reports and yearly monetary policy guidelines published by the National Bank of Poland (NBP).

¹⁶The period from 1995 to 1998 can also be categorized as an inflation targeting lite (ITL) regime, but ITL is not typically classified as a monetary framework. See, for example, Pruski (2002) and Stone (2003).

and Rogoff (2004) and Markiewicz (2006), which are important for the decision of the horizon of the applied data-set. Then, the crawling band was further extended, reaching +/-15% in March 1999. At the end of this process, the crawling band was removed and currency began to float freely in April 2000. While exchange rate interventions were

93	94	95	96	97	98	99	00	01	02	03	04	05	06	07
0	0	1	1	1	1	1	0	0	0	0	0	0	0	0

Note: 0: Float; 1: Intermediate range.

Source: IMF (various issues), Reinhart and Rogoff (2004), Markiewicz (2006).

Table 4.1: De facto exchange rate regimes in Poland from 1993 to 2007.

90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07
1	1	2	2	2	3	3	3	3	3	$3 \rightarrow 4$	4	4	4	4	4	4	4

Note: 1: Peg to a currency or to a basket with fluctuation margins less than, or equal to 2.25%; 2: Crawling peg with fluctuation margins of less than, or equal to 2.25%; 3: Crawling peg with fluctuation margins of more than 2.25%; 4: Free float without any intervention. *Source:* IMF (various issues), Egert and Morales-Zumaquero (2008).

Table 4.2: Exchange rate regimes in Poland from 1990 to 2007.

gradually reduced ending in the free float currency regime, the importance of exchange rate policies of the NBP decreased as well. Thus, the direct target inflation regime (or full-fledged inflation targeting regime) was adopted at the beginning of 1999, though the targets were already determined in June 1998. The different target intervals for the inflation rate are illustrated in Table 4.3.

The NBP introduced a medium-term monetary strategy in order to achieve inflation expectations that are required to join the European Union and set two inflation targets. On the one hand, a short-term target with an outlook of one year, which ranged from 5.4% to 6.8% by the end of 2000, was defined. On the other hand, the medium-term inflationary target was to lower the inflation rate to a level below 4% by the year 2003. In the following years, inflation continued to fall even faster than expected, so the targets could be substantially lowered, but in July 2000, the CPI peaked again with more than 11%. Consequently, the inflation target range had to be raised again to 6-8% for 2001. Henceforth, the NBP reduced inflation targets steadily. After inflation

End-Year	Target	Actual
1999	6.6% - 7.8%	9.8%
2000	5.4% - 6.8%	8.5%
2001	6.0% - 8.0%	3.7%
2002	4.0% - 6.0%	0.7%
2003	3.0% (+/- 1.0%)	1.8%
2004	2.5% (+/- 1.0%)	4.3%
2005	$2.5\% \ (+/- \ 1.0\%)$	0.5%
2006	$2.5\% \ (+/- \ 1.0\%)$	1.4%
2007	$2.5\% \ (+/-1.0\%)$	3.9%

Source: Jonas and Mishkin (2003) and Quarterly Inflation Reports of the NBP.

Table 4.3: Targeted and actual inflation (CPI) in Poland.

had been brought down to a low level, the NBP decided to formulate the inflation target differently. That is why in its Monetary Policy Strategy beyond 2003, the NBP adopted a permanent inflation target¹⁷ set at 2.5% with a symmetrical tolerance range for deviations of +/-1%. In February 2004, the NBP confirmed the fundamental elements of the monetary policy strategy beyond 2003, i.e., inflation target levels, the width of the tolerance range for deviations from the target, and maintaining the floating exchange rate regime until Poland's accession to the European Exchange Rate Mechanism II.

In the following subsections, the treatment of these regime-shifts in the data and, therefore, the specifications of the econometric model are based on the discussion above.

¹⁷The notion of permanent target refers to year-on-year inflation that is measured each month in relation to the corresponding month of the preceding year. By contrast, in the period from 1999 to 2003 it was evaluated only once a year.

Date	Regime
January 1990	Fixed exchange rate against the US \$ (after a 31.6% devaluation on 1 January 1990)
May 1991	Fixed rate against a basket of 5 currencies (after a 17% devaluation). Currency basket: 45% US \$, 35% DM, 10% UK £, 5% French Franc, 5% Swiss Franc
October 1991	Crawling peg, pre-announced crawling devaluation at a monthly rate of 1.8%
February 1992	10.7% devaluation
August 1993	7.4% devaluation; monthly crawling rate $1.6%$
September 1994	Monthly crawling rate 1.5%
November 1994	Monthly crawling rate 1.4%
February 1995	Monthly crawling rate 1.2%
May 1995	Crawling band, widened band $(+/-7\%)$, same crawling rate
December 1995	6% revaluation
January 1996	Monthly crawling rate 1.0%
February 1998	Band widened to $+/-10\%$, monthly crawl 0.8%
July 1998	Monthly crawling rate 0.65%
September 1998	Monthly crawling rate 0.5%
October 1998	Band widened to $+/-12.5\%$
January 1999	New currency basket: 55% Euro, 45% US
March 1999	Band widened to +/- 15%, monthly crawling rate 0.3%
April 2000	Free float

Source: Adapted from Nuti (2000).

Table 4.4: Detailed exchange rate regimes in Poland from 1990 to 2007.

4.3.2 Study Design and Data-Set

In our model, currency risk and possible hedging strategies depend crucially on the joint distribution of the random variables $\tilde{\epsilon}_{h,t}$, $\tilde{\epsilon}_{f,t}$, and \tilde{u}_t , $t = 1, \ldots, T$. According to Chapters 2 and 3, a typical framework for such an analysis is a cointegrated VAR model. The required moments of the random variables $\tilde{\epsilon}_{h,t}$, $\tilde{\epsilon}_{f,t}$, and \tilde{u}_t , $t = 1, \ldots, T$, are quantified and currency risk and possible hedging strategies are determined according to Section 4.2 using a specified and estimated VAR model for two countries.

The data-set used for the estimation of the cointegrated VAR model is retrieved from the International Financial Statistics database (CD ROM, 3/2007) of the IMF and the Datastream database. It consists of monthly (production) price levels and exchange rates for Germany and Poland over the period from January 1994 to December 2007. Although the data period is rather short for such an econometric approach, 168 observations of each data series is a suitable amount for the following estimations and represents the latest possible data-set available for this study. Even though the Polish Zloty could be identified as at least managed floating since 1993 according to the discussion in the former subsection, data before 1994 is not taken into account, since effects of the 1992-1993 Exchange Rate Mechanism crisis should not be contained in the data-set.¹⁸ As proxies for product prices and costs we again use PPIs. The exchange rate (end-of-month rates) between Germany and Poland is treated in the same way as in Chapters 2 and 3. In contrast to the former two chapters, interest rates are not incorporated because they do not improve the information quality of the model. Figure 4.12 in the Appendix shows that the Polish three-month Treasury Bill Rate strongly decreases during the period investigated, so its inclusion would only create a general negative trend in the model.

An overview of the time series underlying our analysis is given by Figures 4.8 to 4.10 in the Appendix. The figures strongly indicate that the series are non-stationary. The integration and cointegration properties of the different series are of major importance for understanding of currency risk in Poland and possible hedging strategies. In the next subsection, these properties are carefully considered in the specification of the econometric model.

¹⁸Choice of this data period is supported by comments of officials at the NBP.

Furthermore, we use the same data for the risk-free interest rates $r_{h,t}$ as in Chapters 2 and 3. In the case of $r_{f,t}$, we use the Polish interpolated zero curve yields for the respective maturity, which is obtained from Datastream.

4.3.3 Specification of the VAR Model

As in the previous chapters, a p-dimensional cointegrated VAR model with k lags is defined according to Equation (2.18). In the econometric model the vector Y_t consists of three variables. The (monthly) inflation rates Δp_h and Δp_f are used to represent the uncertainty of revenues and costs in the model and the absolute deviation from PPP, ppp,¹⁹ represents exchange rate uncertainty. In this approach, the vector Y_t takes the following form:²⁰

$$Y_t = \begin{pmatrix} ppp_t \\ \Delta p_{f,t} \\ \Delta p_{h,t} \end{pmatrix}.$$
(4.12)

	ADF test (t statistics)	KPSS test
Δp_h	-2.40162	0.543^{**}
Δp_{PO}	-2.42739	1.201^{***}
ppp_{PO}	-1.77525	1.293^{***}

Note: For the ADF tests, *, **, and *** mean that the null hypothesis of non-stationarity is rejected at a confidence level of 90%, 95%, and 99%. The corresponding critical values are -3.451, -2.870, and -2.571 assuming no linear trend. For the KPSS tests, *, ** and *** mean that the null hypothesis of stationarity is rejected at a confidence level of 90%, 95%, and 99%. The lag truncation parameter is set to 8 according to Kwiatkowski et al. (1992), p. 174, since at this value the test settles down. The critical values are 0.347, 0.463, and 0.739 assuming no linear trend in the data.

Table 4.5: Unit root tests.

As in Chapters 2 and 3, we apply ADF and KPSS tests to identify integration properties. Test results of Table 4.5 suggest that all time series are best described

¹⁹The time series behavior of this variable is illustrated in Figure 4.11.

²⁰Centered seasonal dummies are used to capture the seasonal effects of the data, because the time series are not seasonally adjusted.

as I(1) processes. Moreover, a graphical inspection of the series confirms these results, which are in line with the findings of similar studies in the literature.²¹

In the next step of the model specification, we must determine the lag length of the VAR model. The information criteria of Hannan-Quinn and Schwarz suggest a lag length of one, as given in Table 4.6. However, with a lag length of one, some autocorrelation remains in the residuals, which is reported in the third and fourth rows of Table 4.6. Further lag reduction tests also indicate an optimal lag length of two,²² so finally, we choose two lags.²³

information criterion	$\operatorname{VAR}(1)$	$\operatorname{VAR}(2)$	VAR(3)	VAR(4)	VAR(5)
Schwarz	-37.726	-37.569	-37.365	-37.169	-36.926
Hannan-Quinn	-38.541	-38.486	-38.383	-38.290	-38.148
LM(1) (p-values)	0.024	0.138	0.188	0.533	0.381
LM(k) (p-values)	0.024	0.919	0.540	0.560	0.659

Note: k represents the lag length of the VAR model.

Table 4.6: Determination of the lag length.

Graphs of the differenced variables in the Appendix show that the underlying normality assumption is not valid for many of the marginal processes. Thus, we control for possible intervention effects conducting a few additive outlier corrections²⁴ and using innovational dummies²⁵.²⁶

In the next step, we must decide on the cointegration rank. For this purpose, Table 4.7 reports the results of the trace test, which show that the two largest eigenvalues are significantly different from zero. Inspection of the third cointegration relation and the number of roots of the companion matrix in Table 4.8 support a cointegration rank of two. Thus, the cointegration rank is set to two, although this case does not seem

 $^{^{21}}$ See Stazka (2007).

 $^{^{22}\}mathrm{These}$ test results are not shown here.

 $^{^{23}\}mathrm{See}$ also Juselius (2006), p. 72, who stresses that a model with two lags is often the best starting point.

²⁴Additive outliers strongly indicate measurement errors and corresponding dummies are applied for the time series of the inflation rates in January 2001, April 2004, December 2004, for Poland.

²⁵Unrestricted permanent and transitory intervention dummies are used if a residual larger than $|3.5 \sigma_{\xi}|$ can be related to a known intervention.

 $^{^{26}}$ A detailed description of the dummies is available in Table 4.13 of the Appendix.

plausible a priori. In comparison to the models of Chapters 2 and 3, the cointegration rank is unchanged, but this finding supports our hypothesis that in high-inflation economies prices and exchange rates tend to cointegrate more strongly.

p-r	r	Eig.Value	Trace	Trace*	Frac95	P-Value	P-Value*
3	0	0.240	65.495	64.063	24.177	0.000	0.000
2	1	0.095	20.114	19.726	12.372	0.002	0.002
1	2	0.021	3.580	3.453	4.156	0.070	0.075

Note: *=trace test statistics and p-values are based on the Bartlett small-sample correction.

Table 4.7: Rank determination tests (trace test).

Rank	ρ_1	ρ_2	$ ho_3$
r = 1	1	1	0.601
r = 2	1	0.807	0.606
r = 3	0.995	0.807	0.606

Table 4.8: Modulus of the five largest roots of the companion matrix for different cointegration ranks.

Tests for autocorrelation:							
LM(1)	0.222						
LM(2)	0.878						
Test for Normality	0.007						
Tests for ARCH:							
LM(1)	0.415						
LM(2)	0.352						

Table 4.9: Misspecification tests: p-values of the corresponding test statistics.

Finally, we conduct several misspecification tests to the estimated cointegrated VAR model. Table 4.9 shows the results of these tests. The multivariate LM test statistics for first and second order residual autocorrelation are far from being rejected, so the

model does not contain autocorrelation. Although Table 4.9 shows that multivariate normality is violated, non-normality is a less serious problem for the estimation results since the univariate misspecification tests, which are not reported here, indicate that the rejection of normality results from excess kurtosis and not skewness. Further tests on parameter constancy support the constancy of the parameters in the chosen, reduced rank VAR models.

At the end of the model specification, we obtain a model of the dynamics of prices and exchange rates that is econometrically well specified and economically reasonable, as Table 4.14 shows.

4.3.4 Results

SD	1 month	6 months	1 year	2 years	3 years	4 years	5 years
"HOME"	0.0	0.0	0.0	0.0	0.0	0.0	0.0
"FOR"	2.0	5.4	8.0	11.8	15.0	18.1	21.0
"FOR+H"	0.5	2.4	4.4	7.3	9.5	11.4	13.1

Table 4.10: Risk (standard deviation) of the real profit in percent in the case of "HOME", "FOR", and "FOR+H" for different time horizons.



Figure 4.1: Risk (standard deviation) of the real profit in percent for the cases "FOR" and "FOR+H" over different time horizons.



Figure 4.2: Costs in Euros for one Zloty production costs for the cases "FOR" and "FOR+H" over different time horizons. For each pair of boxplots, the left one belongs to the "FOR" case and the right one to the "FOR+H" case. On December, 31, 2007: 1 Zloty = 0.28 Euro.

In Section 4.2, we theoretically discuss which risks emerge in the considered cases. As Equation (4.4) shows, the firm faces no risk in real terms in the "HOME" case. Now, we investigate the amount of risk in the cases of "FOR" and "FOR+H" which are estimated in the VECM from the previous section. The results are shown in Figures 4.1 and 4.2, as well as in Table 4.10. The first major finding is that the currency risk of the shift in production to Poland can be large in the "FOR" case. For already short perspectives, the standard deviation achieves high values, such as 8% for a one-year horizon. This means that, with respect to a simple interval estimator, expected real profit can fluctuate within a range of +/-16% in one year. For a five-year horizon, the standard deviation of real profit obtains a value of 21%; hence, considering again the interval estimator, real profit can fluctuate in an interval of +/-42%. In fact, a loss of almost one half of real profit is possible with considerable probability over a five-year time horizon. In addition, Figure 4.5 shows that the only risk factor of real profit in

the "FOR" case, the change in the relative exchange rate \tilde{u}_t , increases exponentially, and in consequence, the risk of real profit also increases exponentially within the time horizon.²⁷ Considering costs, as displayed in detail in Figure 4.2, expected costs are higher for longer, rather than for shorter, horizons, so real profits are reduced, on average, and bear a further disadvantage in addition to high currency risk.

These significant currency risks motivate an application of hedging instruments, which are included in the "FOR+H" case. The second major finding of this chapter is that, in the "FOR+H" case, FX forward use reduces currency risk substantially, but a considerable amount of currency risk still remains. This finding is shown in Figures 4.1, 4.2, and 4.3, as well as in Tables 4.10 and 4.11.



Figure 4.3: Hedging performance using the Johnson measure.

JM	1 month	6 months	1 year	2 years	3 years	4 years	5 years
Polish Zloty	0.950	0.806	0.694	0.616	0.600	0.601	0.610

Table 4.11: Hedging performance using the Johnson measure.

Even for short time horizons, possible reduction of currency risk is limited. For instance, considering a one-year perspective, about 30% of the original currency risk remains. This represents poor hedging efficiency in comparison to the results of Chapters 2 and

²⁷In Chapter 2, the variance of the change in the relative exchange rate \tilde{u}_t rises linearly with the time horizons in the cases of the US, the UK, and Japan.

3. With respect to a simple interval estimator, real profits still fluctuate within a range of +/-9% for a one-year hedge horizon and +/-26% for a five-year hedge horizon. However, currency risk in the "FOR+H" case is significantly lower in comparison to the "FOR" case. Additionally, the expected costs of the "FOR+H" case in Figure 4.2 are lower for time horizons of at least one year, so real profits are higher, on average, using an FX forward. This is only a minor effect that results from the non-zero expected returns of the FX forwards, given the chosen pricing model in Equation (2.8).

Thus, the practical implication for a company dealing with relocation of its production to a foreign country is that currency risk should be considered in the corporate strategy, especially over a long-term horizon. A firm should not only examine the absolute cost reductions available from foreign currency, since the cost savings can be reduced significantly in terms of notional values. Apart from these considerations, however, other possible problems such as quality reductions or the losses of flexibility may also exist.²⁸ Unfortunately, currency risk can only be partially reduced using an FX hedge. As a consequence, a firm with production in Poland faces a certain amount of currency risks, regardless of its risk management activities. In fact, the firm's cost savings as a result of production relocation are risky due to FX changes, which can cut the cost savings considerably. In light of the survey results of Bates (2005) and Kinkel, Dachs, and Ebersberger (2007), that one third of the German firms that have shifted their production to Eastern countries move their production facilities back to Germany, such high currency risk is an important consideration of corporate strategy.

HR_t^*	1 month	6 months	1 year	2 years	3 years	4 years	5 years
Polish Zloty	0.93	0.77	0.67	0.60	0.57	0.55	0.53

Table 4.12: Hedge ratios HR_t^* for different hedge horizons.

The driving forces of low hedge efficiencies are in line with the findings of Chapters 2 and 3: One main driving force for the decreasing term structure of the currency hedge ratios in Chapter 2 is the natural hedge of exchange rate risk. However, this aspect has low influence on lower hedge efficiency; it only causes lower currency hedge ratios in Table 4.12 because the positive correlation between the cost risk $(1/(1 + \tilde{\epsilon}_{f,t}))$ and

 $^{^{28}\}mathrm{See},$ for instance, Bates (2005) and Kinkel and Maloca (2008).


Figure 4.4: Correlations between risk factors.

the relative exchange rate changes $(1 + \tilde{u}_t)$ implies that forwards are effectively more sensitive to changes in real exchange rates than real profits are, which is illustrated in Figure 4.4.

The major driving forces for low hedge efficiency are the unhedgable risks that are caused by very high price fluctuations. These are high for short hedge horizons and amount to a notable part of the original currency risk. Figures 4.5 and 4.6 show this effect. In contrast to the results of Chapter 2, the property that the prices follow I(2) processes is not important here, since the variance ratios are already immense for short hedge horizons, as Figure 4.6 indicates. Of course, as discussed in Chapter 3, additional hedging instruments such as inflation and interest-rate derivatives could improve hedge efficiency, but trading frictions might complicate use of these products in such markets.

The term structure of hedge ratios in Figure 4.7 and Table 4.12 also reflect this effect in the way that, even for short hedge horizons, the term structure of currency hedge ratios is strongly downward sloping, but settles on a level of approximately 60% for long hedge horizons.



Figure 4.5: Variances of risk factors.



Figure 4.6: Variance ratios $\frac{1+\tilde{\epsilon}_{f,t}}{1+\tilde{u}_t}$.



Figure 4.7: The term structure of currency hedge ratios.

4.4 Conclusion

In this chapter, the exchange rate risk brought about by shifting production to foreign countries is investigated. For that purpose, different cases of a firm within different production strategies are derived and analyzed. In the next step, the currency risks of these cases are quantified for different time horizons in an empirical study. Based on a cointegrated VAR model of prices and the exchange rate, we simulate future paths by means of a bootstrap algorithm. The term structure of currency risk is thus obtained using these paths.

Our empirical study provides three major results. First, it indicates additional risks that result from offshoring. In real terms, the relocation of production causes currency risks that are only originated by uncertain relative exchange rate changes, which are independent of price level behaviors. Second, the empirical study shows that the currency risk that is induced by offshoring can be enormous and depends heavily on the time horizon. Third, a hedging strategy using FX forward contracts to overcome currency risk is not as efficient as in Chapter 2, but, at least, it reduces the FX risk to some extent. This low hedging efficiency is the result of high basis risk that is due to high inflation in the foreign country. In a nutshell, this chapter highlights that a firm should consider carefully the aspects of currency risk that arise when relocating its production to a foreign country in order to avoid backshoring its production. Furthermore, financial hedges are not particularly efficient in typical offshoring target countries, which are typically characterized by low labor costs.

4.5 Appendix



(c) Second difference

Figure 4.8: Overview of time series: Log PPI of Germany.



(c) Second difference

Figure 4.9: Overview of time series: Log PPI of Poland.



Figure 4.10: Overview of time series: Log FX.



Figure 4.11: Overview of the absolute purchasing power parity ppp.



Figure 4.12: Three-month Treasury Bill Rates in levels (monthly) in Poland and Germany.

-

Dummy	Explanation		
Permanent			
1996:01	Reduction of discount rate from 3.50% to 3.00% in a process of		
	several cuts in interest rates		
1997:03	NBP's actions aiming at reducing the disproportion between the		
	rate of domestic demand increase and the rate of supply increase		
1998:08	Changes in monthly crawling rate		
1999:01	Introduction of the Euro		
2001:07	Sharp Zloty depreciation		
2001:10	Reduction of ECB's interest rates for main refinancing operations		
	from 4.50% to 3.75% ; huge interest rate speculations; terrorist		
	attacks on September 11, 2001		
2003:04	NBP's announcement of reduction of discount and lombard rate		
2003:09	Strong uncertainty with respect to the public finance perspectives		
	and the effect of the Euro appreciating against the US $\$		
	on the global markets (the Euro/US $\$ exchange rate improved		
	from 1.08 at the beginning of September to 1.14 in the last		
	week of September)		
2004:06	Huge increases in the price of fuel and foodstuffs and an increase		
	in tax rates for indirect taxation and other related factors		
	including an increase in the demand for Polish foodstuffs.		
т • /			
Transitory			
1995:01	Reduction of monthly crawling rate to 1.2%		

POLAND

Table 4.13: Description of the dummies.

POLAND

ppp_t	$\Delta p_{f,t}$	$\Delta p_{h,t}$
1.000	-1.085	0.000
[NA]	[-10.493]	
0.000	[NA] 1.000	-3.375
	[1,1]	[1.014]
Alpha	a(1) Alp	ha(2)
0.00)2 -().001
[0.58]	64] [-0	0.623]
0.23	30 0.	.021
[3.82		.610]
U.1 8 [5.12		150 039]
[0.12	ioj [1	.000]
ppp_t	$\Delta p_{f,t}$	$\Delta p_{h,t}$
0.002	-0.003	0.004
$\underset{[0.584]}{0.002}$	-0.003 [-1.130]	$\underset{[0.623]}{0.004}$
0.002 [0.584] 0.230	-0.003 [-1.130] -0.228	$\begin{array}{c} 0.004 \\ {}_{[0.623]} \\ -0.072 \end{array}$
0.002 [0.584] 0.230 [3.823]	-0.003 [-1.130] -0.228 [-4.287]	$\begin{array}{c} 0.004 \\ \scriptstyle [0.623] \\ -0.072 \\ \scriptstyle [-0.610] \end{array}$
0.002 [0.584] 0.230 [3.823] 0.186	$\begin{array}{c} -0.003 \\ [-1.130] \\ \textbf{-0.228} \\ [-4.287] \\ -0.052 \\ [-1.698] \end{array}$	$\begin{array}{c} 0.004\\ [0.623]\\ -0.072\\ [-0.610]\\ \textbf{-0.505}\\ [7,030]\end{array}$
0.002 [0.584] 0.230 [3.823] 0.186 [5.128]	$\begin{array}{c} -0.003 \\ [-1.130] \\ \textbf{-0.228} \\ [-4.287] \\ -0.052 \\ [-1.628] \end{array}$	$\begin{array}{c} 0.004 \\ \scriptstyle [0.623] \\ -0.072 \\ \scriptstyle [-0.610] \\ \textbf{-0.505} \\ \scriptstyle [-7.039] \end{array}$
0.002 [0.584] 0.230 [3.823] 0.186 [5.128]	$\begin{array}{c} -0.003 \\ [-1.130] \\ \textbf{-0.228} \\ [-4.287] \\ -0.052 \\ [-1.628] \end{array}$	$\begin{array}{c} 0.004 \\ [0.623] \\ -0.072 \\ [-0.610] \\ \textbf{-0.505} \\ [-7.039] \end{array}$
$0.002 \\ [0.584] \\ 0.230 \\ [3.823] \\ 0.186 \\ [5.128] \\ \hline ppp_{t-1}$	$\begin{array}{c} -0.003 \\ [-1.130] \\ \textbf{-0.228} \\ [-4.287] \\ -0.052 \\ [-1.628] \end{array}$	$\begin{array}{c} 0.004 \\ \scriptstyle [0.623] \\ \scriptstyle -0.072 \\ \scriptstyle [-0.610] \\ \scriptstyle \textbf{-0.505} \\ \scriptstyle [-7.039] \end{array}$
$\begin{array}{c} 0.002 \\ [0.584] \\ \textbf{0.230} \\ [3.823] \\ \textbf{0.186} \\ [5.128] \\ \hline \\ ppp_{t-1} \\ 0.117 \end{array}$	$\begin{array}{c} -0.003 \\ [-1.130] \\ \textbf{-0.228} \\ [-4.287] \\ -0.052 \\ [-1.628] \\ \hline \Delta^2 p_{f,t-1} \\ 0.000 \end{array}$	$\begin{array}{c} 0.004 \\ {}_{[0.623]} \\ -0.072 \\ {}_{[-0.610]} \\ \textbf{-0.505} \\ {}_{[-7.039]} \\ \hline \\ \hline \\ \Delta^2 p_{h,t-1} \\ -0.007 \end{array}$
$\begin{array}{c} 0.002 \\ [0.584] \\ \textbf{0.230} \\ [3.823] \\ \textbf{0.186} \\ [5.128] \\ \hline ppp_{t-1} \\ 0.117 \\ 1.668] \end{array}$	$\begin{array}{c} -0.003 \\ [-1.130] \\ \textbf{-0.228} \\ [-4.287] \\ -0.052 \\ [-1.628] \\ \hline \Delta^2 p_{f,t-1} \\ 0.000 \\ [0.060] \end{array}$	$\begin{array}{c} 0.004 \\ \scriptstyle [0.623] \\ -0.072 \\ \scriptstyle [-0.610] \\ \textbf{-0.505} \\ \scriptstyle [-7.039] \end{array}$
$\begin{array}{c} 0.002 \\ [0.584] \\ \textbf{0.230} \\ [3.823] \\ \textbf{0.186} \\ [5.128] \\ \hline ppp_{t-1} \\ 0.117 \\ 1.668 \\ 2.857 \\ \hline \end{array}$	$\begin{array}{c} -0.003 \\ [-1.130] \\ \textbf{-0.228} \\ [-4.287] \\ -0.052 \\ [-1.628] \end{array}$ $\begin{array}{c} \Delta^2 p_{f,t-1} \\ 0.000 \\ [0.060] \\ \textbf{-0.129} \end{array}$	$\begin{array}{c} 0.004 \\ \scriptstyle [0.623] \\ \scriptstyle -0.072 \\ \scriptstyle [-0.610] \\ \scriptstyle \textbf{-0.505} \\ \scriptstyle [-7.039] \end{array}$
$\begin{array}{c} 0.002 \\ [0.584] \\ \textbf{0.230} \\ [3.823] \\ \textbf{0.186} \\ [5.128] \\ \hline \\ ppp_{t-1} \\ \hline \\ \textbf{0.117} \\ 1.668] \\ \textbf{0.857} \\ 1.980] \\ \textbf{0.452} \end{array}$	$\begin{array}{c} -0.003 \\ [-1.130] \\ \textbf{-0.228} \\ [-4.287] \\ -0.052 \\ [-1.628] \end{array}$	$\begin{array}{c} 0.004 \\ [0.623] \\ -0.072 \\ [-0.610] \\ \textbf{-0.505} \\ [-7.039] \end{array}$
	$\begin{array}{c} ppp_t \\ 1.000 \\ [NA] \\ 0.000 \\ [NA] \\ \end{array}$ Alpha 0.00 0.58 0.22 0.18 [5.12] 0.18 [5.18] 0.18 [5.18] 0.18 [5.18] 0.18 [5.18] 0.18 [5.1	$\begin{array}{c c} ppp_t & \Delta p_{f,t} \\ \hline 1.000 & \textbf{-1.085} \\ [NA] & [-10.493] \\ 0.000 & 1.000 \\ [NA] & [NA] \\ \hline \end{array} \\ \hline \\ Alpha(1) & Alp \\ 0.002 & -0 \\ [0.584] & [-0] \\ 0.230 & 0, \\ [3.823] & [0] \\ 0.186 & 0, \\ [5.128] & [7] \\ \hline \end{array} \\ \hline \\ ppp_t & \Delta p_{f,t} \\ \hline \end{array}$

Note: t-statistics in brackets. Significant test statistics are given in **bold** face.

Table 4.14: Long-run and short-run structure of the VECM model for Poland.

Chapter 5

Conclusion and Outlook

In the light of recent immense losses caused by currency fluctuations and the tightening of financial reporting rules, non-financial firms are becoming increasingly aware of exchange rate risks and the importance of an adequate risk management Those risk management programs require comprehensible instructions program. for the application of appropriate hedging instruments. However, existing FX risk management literature lacks concrete, theory-based guidance for corporate risk management. Thus, this dissertation contributes to the field of research in three major aspects: (1) It sheds light on maturity effects of exchange rate risk management and shows that long-term hedging with currency forwards is less important than short-term hedging. (2) The efficiency of an FX hedge in real terms can be significantly improved for short hedge horizons by using additional inflation derivatives and for long hedge horizons by adding long-term interest rate derivatives. (3) For the case of Poland, the production relocation can cause tremendous currency risk that can only be partially reduced using an adequate hedging strategy. However, the three studies in this dissertation leave sufficient room for additional future research.

In each study, we examine a firm with revenues and costs that grow in line with the price level (PPI) of the respective country. Therefore, the results of this dissertation can be considered a type of country benchmark. Of course, specific firms will generally differ from this benchmark and might even experience stronger effects of their hedging strategies. Examination of this conjecture would be an interesting extension of our studies and offer promising opportunity for future research. One could use industry-specific price indices for the implementation of hedging strategies or even firm-specific information, if available.

Another open issue is the determination of the hedge positions for decision criteria, other than variance-minimization, which is already partially completed in Subsection 2.3.4 of the present dissertation. Under more general criterion functions, forward contracts will in general no longer be optimal hedging instruments. As shown by Moschini and Lapan (1995) and Brown and Toft (2002) in the context of specific models, some kinds of options should be added to forward positions. Thereby, Adam (2003, 2008) shows why and how firms use nonlinear hedging strategies. For instance, in Chapter 3, inflation derivatives with a non-linear payoff structure like options could perform better for longer hedge horizons than the inflation forwards considered in the current dissertation.

Finally, it would be interesting to understand what consequences a firm must consider that hedges different exchange rate risks simultaneously. Studies such as those of Kwok (1987) and Giaccotto, Hedge, and McDermott (2001) note that a firm that deals with each particular currency risk separately might systematically over- or underhedge relative to the overall variance-minimizing hedge. This fact is caused by potential correlations between exchange rates. The need to measure risk and exposure in a portfolio context is evidenced by the increased popularity of value-at-risk products, such as Creditmetrics, which use a variance-covariance matrix of all positions to determine overall exposure. Exchange rate risk management, therefore, can be more effective in a general framework that recognizes the interactions between different currency exposures and currency-specific hedges. For this purpose, Giaccotto, Hedge, and McDermott (2001), for instance, provide a hedging model for a firm with two pairs of price and quantity exposures and find potential gains in hedging efficiency.

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