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## Hedging export revenue risk using futures and options

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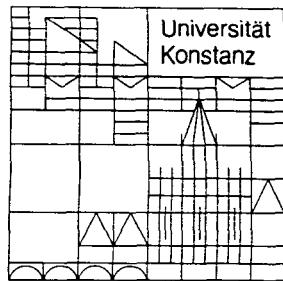
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Juristische  
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**Hedging Export Revenue Risk  
Using Futures and Options**

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**HEDGING EXPORT REVENUE RISK  
USING FUTURES AND OPTIONS**

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**Serie II - Nr. 143**

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# Hedging Export Revenue Risk Using Futures and Options

by  
**Udo Broll and Jack E. Wahl\***

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## **Abstract**

This paper presents a model of a competitive risk-averse exporting firm under exchange rate risk. We show that export and hedging decisions can be separated if futures and currency options are available. A full hedge of uncertain export revenue occurs if the futures market is unbiased and the currency option premium is fair. Furthermore, institutional aspects of introducing hedging markets are presented.

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# 1 Introduction

Since the collapse of the Bretton Woods agreement in 1973 the decisions of international firms have been made in an environment of highly uncertain exchange rates. Thus for exporting and importing firms the need to manage foreign currency risk has increased substantially (see KRUGMAN [1989], SHAPIRO [1989], FRANKE [1991]). At the same time a variety of hedging instruments such as currency futures and currency options are being offered by financial agents. However futures and option markets may not only provide insurance against price and exchange rate fluctuations, but also provide opportunities for speculation (see STREIT [1983], SINN [1989].)

Recently several studies have derived *separation* theorems for international firms facing exchange rate uncertainty (see for example KAWAI and ZILCHA [1986], ELDOR and ZILCHA [1987], BROLL and ZILCHA [1991], BROLL and WAHL [1991], ZILCHA and ELDOR [1991]). In these models, it is assumed that the firm must make production decisions in the current period, but due to different reasons, has to sell its output one period hence. All resources are purchased and allocated in the current period at known prices, but the output revenue one period hence is unknown due to an unknown spot exchange rate. Firms are assumed to hold subjective probability distributions on the future spot exchange rate. A futures market exists on which the international firms can contract to buy or sell foreign exchange today at

a known price.

The main result of these papers is a separation property. That is to say, production and sales decisions are independent of both the exchange rate expectations and the degree of risk aversion of the firm. The forward exchange rate plays a role exactly analogous to that of a certain price in the traditional price theory. Exchange rate expectations and exchange rate uncertainty do play a role in determining the amount of hedging in the futures market. The firm may hedge all his foreign net revenue if the futures market is unbiased (*full hedge*).<sup>1</sup>

The purpose of this paper is to extend the results of the literature to the case where the firm has access not only to futures markets but also to currency option markets. Our paper shows that the basic separation property still holds. But as a result of the more general institutional framework, the implications for the optimal hedge are different. For example, the full hedge theorem is obtained if and only if futures prices are unbiased *and* options prices are fair.

In *section 2* the firm's behavior regarding optimal choice of exports and hedging levels in the futures and currency option markets is studied. In a mean-variance approach a variety of hedging results are derived in *section 3*. *Section 4* considers some institutional implications of introducing missing hedging markets.

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<sup>1</sup>For a detailed discussion of hedging behavior see Bamberg and Baur [1987].

## 2 The Basic Model

Consider a risk-averse, competitive firm which produces a commodity to be exported. The firm produces and exports an amount  $x$  and faces uncertain foreign exchange rate  $\tilde{e}$  but a certain foreign commodity price  $p$ . Furthermore we have the certain interest factor  $r$ , i.e., one plus the riskless interest rate and the certain firm's cost function  $C(x)$ . We assume that  $C(0) = 0$ ,  $C(\cdot)$  is strictly convex, increasing and differentiable, and that the firm always produces a positive amount, i.e.,  $x > 0$ .

Since production takes time the firm may hedge its export revenue risk by selling foreign currency in the futures market at current price  $e_f$  for delivery in one period.<sup>2</sup> Let  $z_f$  be the amount of foreign exchange sold in the futures market, and let a negative  $z_f$  imply that the firm purchases foreign currency in the futures market. On the other hand, the firm may hedge its profit risk by purchasing currency put options on the underlying foreign exchange at the current price  $p_o$ . Let  $z_o$  be the amount of the currency put options contract purchased in the options market, and let a negative  $z_o$  denote that the firm writes currency put options. Furthermore let us denote by  $[b - \tilde{e}]^+ \equiv \max(0, b - \tilde{e})$  the cash inflow the firm will obtain from rationally exercising the put option.

Thus, with futures and option markets available, the stochastic profit of

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<sup>2</sup>Since the interest rate is riskless there is no basis risk, which implies that there is no distinction between futures and forward markets.

the exporting firm one period hence,  $\tilde{\Pi}$ , in domestic currency units can be expressed as the net exposure converted at the future spot exchange rate plus the proceeds from the futures and option market transaction minus the production cost:

$$\tilde{\Pi} = (px - z_f)\tilde{e} + z_f e_f + z_o([b - \tilde{e}]^+ - rp_o) - C(x). \quad (1)$$

The exporting firm obeys the expected utility hypotheses. It maximizes the expected utility of its local-currency profits  $E\{U(\tilde{\Pi})\}$  by choosing  $x$ ,  $z_f$ , and  $z_o$ , where  $E$  is the expectations operator and  $\tilde{\Pi}$  is defined in Eq. (1).

The first-order conditions for an optimum are:

$$x : \quad E\{\hat{U}'(\tilde{\Pi})[\tilde{e}p - C'(x)]\} = 0, \quad (2)$$

$$z_f : \quad E\{\hat{U}'(\tilde{\Pi})(e_f - \tilde{e})\} = 0, \quad (3)$$

$$z_o : \quad E\{\hat{U}'(\tilde{\Pi})([b - \tilde{e}]^+ - rp_o)\} = 0, \quad (4)$$

where  $U'$  is the marginal utility,  $C'$  denotes marginal costs, and  $\hat{U}'$  denotes the standardized marginal utility such that  $\hat{U}'(\tilde{\Pi}) \equiv U'(\tilde{\Pi})/E\{U'(\tilde{\Pi})\}$ .

*Missing hedging markets:* How does export revenue risk affect the exporting firm's decision without hedging markets? We discuss this question by supposing that  $z_f = z_o \equiv 0$  in Eq. (1). Then, if export revenue becomes more risky the risk-averse firm will decrease its output. This can be demonstrated also follows.

Consider the certain foreign exchange rates  $\bar{e}$  and the risky rate  $\tilde{e}$  such that  $\bar{e} = E(\tilde{e})$ , which implies a simple mean preserving spread. Let  $\tilde{\Pi}$  denote

random profit under exchange rate  $\tilde{e}$  and  $x$  ( $x_c$ ) denote output under exchange rate  $\tilde{e}$  ( $\bar{e}$ ). Since profit increases in the exchange rate decreasing marginal utility implies

$$E\{\hat{U}'(\tilde{\Pi})[\tilde{e} - \bar{e}]\} < 0,^3$$

from which we get by multiplying with price  $p$  and extending the inequality by marginal costs  $C'(x)$

$$E\{\hat{U}'(\tilde{\Pi})[\tilde{e}p - C'(x)]\} - E\{\hat{U}'(\tilde{\Pi})[\bar{e}p - C'(x)]\} < 0.$$

Then from Eq.(2) we have

$$\bar{e}p - C'(x) > 0.$$

From this inequality it follows immediately that in order to satisfy the optimum condition under exchange rate  $\bar{e}$ ,  $x_c > x$ , for marginal costs increase with output. This proves

**Proposition 1.** *If the foreign exchange rate becomes risky by preserving its mean at  $\bar{e} = E\{\tilde{e}\}$ , then optimal output of the exporting firm diminishes.*

*Hedging markets:* Let us now show the implications of the existence of hedging markets such as futures and put options. Then the exporting firm can undo the effect of increased export revenue risk by using these hedging instruments. Instead of expectations about the probability distribution of

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<sup>3</sup>Note that  $\bar{e}$  describes the so-called certainty equivalent case (see, e.g., Sandmo [1971], Leland [1972], Kawai and Zilcha [1986]; Eldor and Zilcha [1987]).

the exchange rate and instead of preferences of the firm, a market price will determine optimal output to be exported, that is to say the futures price of foreign exchange.

Multiplying Eq. (3) by the foreign commodity price  $p$  and adding the result to Eq. (2) we get the optimality condition

$$C'(x) = pe_f. \quad (5)$$

This implies the well-known separation result.<sup>4</sup>

**Proposition 2.** *The optimal output to be exported does not depend upon the firm's risk aversion nor does it depend upon the firm's expectations of the spot rate of foreign exchange.*

Note that the separation result holds in a situation where two different hedging instruments are available. Especially we observe that neither the striking price  $b$  nor the premium of the put option  $p_o$  have any impact on the export decision. The only data from hedging markets which is influencing the optimal export is the futures price  $e_f$ .

**Corollary 1.** *The futures price elasticity of output is inversely related to the elasticity of marginal costs.*

**Proof:** Let  $G(x) \equiv \frac{C''(x)}{C'(x)}x$ , where  $C''(x)$  denotes the derivative of marginal costs. Then implicit differentiation of Eq. (5) shows after straightforward

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<sup>4</sup>See Ethier [1973], Danthine [1978], Holthausen [1979], Katz and Paroush [1979], Feder, Just and Schmitz [1980], Eldor and Zilcha [1987].

manipulations that  $\frac{d \ln x}{d \ln e_f} = \frac{1}{G(x)}.$ <sup>5</sup> ||

### 3 The Mean–Variance Model

In the following we consider a special case of the firm's utility: mean–variance preferences. This specification will allow to reveal interesting properties of the optimal hedging decision of the firm. Of course, the separation property must also hold in this scenario.

The exporter's decision problem is given by

$$\max_{\{x, z_f, z_o\}} E\{U(\tilde{\Pi})\} = \mu - \frac{\alpha}{2} \sigma^2, \quad \alpha > 0, \quad (6)$$

where  $\tilde{\Pi}$  is defined in Eq. (1),  $\mu$  denotes expected profits,  $\sigma^2$  denotes the profit's variance and  $\alpha$  measures risk aversion. If we introduce the definitions

$$g_o \equiv \frac{Cov\{\tilde{e}, -(b - \tilde{e})^+\}}{Var(\tilde{e})} \quad \text{and} \quad h_o \equiv \frac{Cov\{\tilde{e}, -(b - \tilde{e})^+\}}{Var(b - \tilde{e})^+}$$

the first-order conditions can be written as follows:

$$x : \quad E\{\tilde{e}\} - \alpha Var\{\tilde{e}\}[+ px - (z_f + g_o z_o)] = \frac{C'(x)}{p}, \quad (7)$$

$$z_f : \quad E\{\tilde{e}\} - \alpha Var\{\tilde{e}\}[+ px - (z_f + g_o z_o)] = e_f, \quad (8)$$

$$z_o : \quad E\{b - \tilde{e}\}^+ - \alpha Cov\{\tilde{e}, -(b - \tilde{e})^+\}[-px + (z_f + \frac{1}{h_o} z_o)] = rp_o. \quad (9)$$

Before investigating these conditions let us further symplify notation in Eqs. (8) and (9). We introduce

$$s_f \equiv \frac{E\{\tilde{e}\} - e_f}{\alpha Var\{\tilde{e}\}} \quad \text{and} \quad s_o \equiv \frac{E\{b - \tilde{e}\}^+ - rp_o}{\alpha Cov\{\tilde{e}, -(b - \tilde{e})^+\}}. \quad (10)$$

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<sup>5</sup>Example:  $C(x) = \frac{1}{2}x^2$ . Then the elasticity of output with regard to the futures price is 1.

Then Eqs. (8) and (9) can easily be rewritten as the following linear system:

$$\begin{pmatrix} 1 & g_o \\ 1 & \frac{1}{h_o} \end{pmatrix} \begin{pmatrix} z_f \\ z_o \end{pmatrix} = \begin{pmatrix} px - s_f \\ px + s_o \end{pmatrix}. \quad (11)$$

This linear system determines the optimal hedging policy of the firm.<sup>6</sup>

### 3.1 Separation Result

Since separation holds in the basic model it also has to hold in the model with mean-variance preferences. This follows immediately from Eqs. (7) and (8), since the LHS of both equations coincide. Hence  $C'(x) = pe_f$ . Thereby  $x$  represents the optimal **export volume**.

The separation property of the firm's optimal decision making implies that production and hedging decisions can be made in two steps. Therefore we will now concentrate on the optimal hedging given the optimal output to be exported.

### 3.2 Optimal Hedging

In order to determine the optimal hedge portfolio of the firm  $\{z_f, z_o\}$  we concentrate on the demand equations (11). Applying Cramer's Rule to the linear system (11) we obtain the optimal **hedging policy** of the firm:

$$z_f = \frac{-1}{1 - \rho^2} \{s_f + g_o s_o\} + px, \quad (12)$$

$$z_o = \frac{1}{1 - \rho^2} \{s_o + h_o s_f\}, \quad (13)$$

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<sup>6</sup>The interpretation of the definitions used will become clear in the following sections.

where  $\rho^2 \equiv h_0 g_o = \text{Korr}^2\{\tilde{e}, -(b - \tilde{e})^+\}$ . Note that  $\rho^2 < 1$  as long as there are more than two states of nature.<sup>7</sup>

The firm's optimal hedging policy reveals some interesting features which we present in the following.

**Proposition 3.** *Both, the firm's demand for currency put options and its demand for currency futures contracts depend upon expectations and risk aversion of the firm. But though the demand for futures depends upon export revenue the demand for put options does not.*

The proof is a direct result of Eqs. (12) and (13). In this sense the firm will use options only for speculative reasons. This will be the case only if the futures price is biased and/or the put price is not fair.

**Corollary 2.** *The firm will not trade any put option and it will fully hedge its export revenue in the futures market, if and only if the futures price is unbiased (i.e.,  $s_f = 0$ ) and the put price is fair (i.e.,  $s_o = 0$ ).*

Note that  $s_f$  and  $s_o$  represent the 'pure' speculative demand of futures contracts and put options, respectively. The former vanishes if  $e_f = \bar{e}$  and the latter if  $rp_o = E\{b - \tilde{e}\}^+$  (see definitions (10)).

**Proof:** Consider Eqs. (12) and (13). (i) Sufficiency: trivial. (ii) Necessity:  $z_o = 0 \Leftrightarrow s_o + h_0 s_f = 0$ . Hence  $s_f + g_o s_o = s_f + g_o(-h_0 s_f) = s_f(1 - h_0 g_o) = s_f(1 - \rho^2)$  where  $\rho^2 < 1$ . It follows that  $s_f = 0$  if  $z_f = px$ . ||

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<sup>7</sup>If there are two states of nature, then one of the hedging instruments is redundant.

Note that a necessary and sufficient condition for a vanishing put option demand of the firm<sup>8</sup> is given by  $s_o = -h_o s_f$  from Eq. (13). Since the hedge ratio  $h_o$  is positive it follows that the risk premia in both hedging markets must exhibit opposite signs, i.e.,  $\text{sgn}\{s_o\} = -\text{sgn}\{s_f\}$ . As a matter of fact  $h_o > 1$ , so we further observe that the risk premia must be of different magnitude, or,  $|s_o| > |s_f|$ . Hence our scenario requires that the deviation from, respectively, unbiased futures prices and fair option prices will always be greater in the options market.

**Corollary 3.** *If the risk premia in the futures price and in the put price are positive (negative), then the firm's hedging portfolio will over(under)hedge export revenue.*

This follows from the fact that the demand for currency put options more than offsets the reduction in the sale of currency futures contracts.

**Proof:**  $s_o > 0$  and  $s_f > 0 \Rightarrow s_o + h_o s_f > s_f + g_o s_o$ , since  $h_o > 1$  and  $g_o < 1$ . The opposite inequality holds if  $s_o < 0$  and  $s_f < 0$ . ||

Note that this result is in conflict with the literature normally assuming the existence of a currency forward/futures market only. In this market setting a positive (negative) risk premium implies under(over)hedge of export revenue.<sup>9</sup>

**Corollary 4.** *Suppose both hedging instruments exhibit a positive risk pre-*

<sup>8</sup>This is *not* to be confused with a full hedge of export revenue.

<sup>9</sup>See Benninga, Eldor and Zilcha [1985], Kawai and Zilcha [1986], Eldor and Zilcha [1987], and Broll and Zilcha [1991].

*mium. Then if risk aversion increases, the demand for put options will decrease, whereby the sale of futures contracts will increase.*

**Proof:** Since  $s_o$  and  $s_f$  are decreasing in the risk aversion parameter  $\alpha$  and since separation holds, the claim immediately follows from the demand functions (12) und (13).||

## 4 Some Institutional Implications

This paper considers the production and hedging decisions of an international firm facing exchange rate uncertainty. We extend previous work on the export decisions under exchange rate uncertainty by deriving preference-independent export production rules when currency futures *and* currency options are available. The analysis suggests that the development of hedging markets that do not currently exist facilitates the rational decision making of exporting firms and, therefore, cannot lead to less exports.

From an institutional point of view the paper deals with the effect of (non-)missing risk sharing markets. In this respect we investigate the (in)completeness of hedging markets.<sup>10</sup>

First let us focus on the institutional aspects of introducing hedging markets. In the absence of hedging markets, the exporter will have to form expectations about future exchange rates and he will have to formulate his risk

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<sup>10</sup>For a general overview and discussion of missing markets see Hahn [1989] and especially Newbery [1989].

preferences. This will imply high information costs. The paper argues that the availability of hedging markets allows for a substantial reduction in the complexity of the export decision making of the firm.

This can be seen as follows: Consider a world without uncertainty. Then the rational exporting firm equates marginal costs to price. This rule also holds under uncertainty if futures and options are available, the only difference being that the futures price is the relevant price.

The important issue of this finding is that elements of exchange rate uncertainty and attitude towards risk are all irrelevant to the exporter's optimal production decision. Only the firm's cost function has to be assessed. The other factors, i.e. the price of the good in the foreign country and the futures price are market data. Hence the production decision can be taken separately of the hedging decision. The latter, of course, will be influenced by firm-related data like expectations and risk behavior.

It follows that this separation result provides theoretical justification for the real-world division of production and financial departments in international firms. Furthermore, the same line of argument may be used in this context to explain the advantages of the separation of ownership and management, because the profit (or value) maximizing production rule for any publicly held firm is independent of the attitudes towards risk and the exchange rate expectations of its owners. Hence the quantities traded in the international commodity markets does not depend on the organizational structure of the

international firms.

Now let us assume that hedging markets are introduced sequentially. Then substantial institutional effects have to be faced. For example, completing a put option market with currency futures will result in the separation property of the decision process and, as we have already shown, in a reduction in information and organisation costs. Furthermore, this scenario will imply a extrem change in the firm's hedging policy. Though the firm will hedge export revenue using put options at the start, the introduction of a futures market will completely shift the influence of export revenue to the futures contracts. The option will preserve a speculative character only.

On the other hand, completing a futures markets with currency put options will not undermine the advantages of separation in the economy, but it may interfere with the existing hedging policy of the firms. This is easily illustrated if we assume a positive risk premium in the futures market at the beginning. Then it is well-known that the firm will underhedge export revenue. Introducing put options with fair prices, for example, will now cause the firm to *overhedge* export revenue by its hedging *portfolio*.

Summarizing the discussion we conclude that the introduction of institutional arrangements in hedging markets has to be carefully realized.

## Summary

In this note we show that production and hedging decisions of a competitive risk-averse exporting firm can be separated if futures and currency options are available. In a mean-variance framework a full hedge of risky export revenue via futures contracts occurs if and only if the futures market is unbiased and the currency option premium is fair. The institutional implications are twofold: On the one hand, completing a put option market with futures implies separation and, therefore, a reduction in information costs by simplifying the achievement of optimal export policy of the firm. On the other hand, we obtain a *complete* shift in the influence of export revenue from a specific hedging instrument to another. Thus, introducing missing markets may simplify and reorganize optimal export and optimal hedging decisions of an international firm.

## Zusammenfassung

### *Das Hedging des Exporterlösrisikos durch Futures und Optionen*

Maximiert ein exportierendes risikoscheues internationales Unternehmen seinen erwarteten Gewinnutzen, dann führt ein Hedging des Wechselkursrisikos mittels Futures und Verkaufsoptionen dazu, daß die optimale Exportentscheidung unabhängig ist, sowohl von dem Ausmaß der Risikoscheu des Unternehmens, als auch von seinen Wechselkurserwartungen (Separationstheorem). Darüber hinaus ist die optimale Exportentscheidung unabhängig von Daten, die aus dem Options-Kontrakt in die Exportentscheidung einfließen könnten, also Basiskurs und Optionspreis. Vielmehr bestimmen Grenzkosten, ausländischer Güterpreis und Devisenterminkurs das optimale Exportvolumen. Es zeigt sich, daß das Exportvolumen das

optimale Hedging des internationalen Unternehmens ausschließlich mittels Futures-Kontrakten beeinflußt. Stimmt der Futures-Preis mit dem erwarteten zukünftigen Devisenkassakurs und der aufgezinste Optionspreis mit dem erwarteten zukünftigen Ausübungsgewinn überein, dann handelt das internationale Unternehmen keine Verkaufsoptionen und hedgt den gesamten Exporterlös mittels Verkauf von Futures (Full Hedging-Theorem). Des weiteren zeigt sich in bezug auf die Ausgestaltung institutioneller Rahmenbedingungen, daß die Einführung von Futures-Märkten ausgehend von Verkaufsoptionen zwei Effekte hat: Zum einen vereinfacht sich die optimale Exportentscheidung des internationalen Unternehmens bezüglich der Datenbeschaffung, weil alle entscheidungsrelevanten Daten jetzt beobachtbar sind, zum zweiten verlagert sich der Einfluß des Exporterlöses von einem Hedginginstrument *vollständig* auf ein anderes, nämlich hier von der Verkaufsoption auf den Future.

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