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Summary

In this paper we discuss a simple econometric strategy for pricing and hedging illiquid financial products, such as the Japanese crude oil cocktail (JCC) index, the most popular OTC energy derivative in Japan. First, we review the existing literature for computing optimal hedge ratios (OHR) and we propose a critical classification of the existing approaches. Second, we compare the empirical performance of different econometric models (namely, regression models in price-levels, price first differences, price returns, as well as error correction and autoregressive distributed lag models) in terms of their computed OHR using monthly data on the JCC over the period January 2000-January 2006. Third, we illustrate and implement a procedure to cross-hedge and price two different swaps on the JCC: a one-month swap and a three-month swap with a variable oil volume. We explain how to compute a bid/ask spread and to construct the hedging position for the JCC swap. Fourth, we evaluate our swap pricing scheme with backtesting and rolling regression techniques. Our empirical findings show that it is not necessary to use sophisticated econometric techniques, since the price level regression model permits to compute a more reliable optimal hedge ratio relative to its competing alternatives.

Keywords: Hedging Models, Cross-Hedging, Energy Derivatives, Illiquid Financial Products, Commodity Markets, JCC Price Index

JEL Classification: G13, G15

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1 Introduction

It is well known that hedging aims at reducing the risk involved in holding a financial asset by taking an exactly offsetting position. In particular, hedging is the most important risk management approach used by a company to reduce its exposure to fluctuations in commodity prices.

The aim of this paper is to explain and analyse the risk associated to illiquid financial products.[1] Dealing with the risk associated to illiquid financial products always involves a basis risk, since a perfect hegde is not possible due to the lack of a related futures market. In this case, the only way to hedge a position is to find a product which is highly correlated with the underlying; in other words, it is necessary to find a market which is very similar to the original one. This procedure is known as cross-hedging, i.e. hedging a product in a different, though related, futures market.

The main contribution of this paper is to discuss a simple econometric strategy for pricing and hedging illiquid products, such as the Japanese crude oil cocktail (JCC) index, the most popular OTC energy derivative in Japan. We review the existing literature for computing optimal hedge ratios (OHR) and we propose a critical classification of the existing approaches. We compare the empirical performance of different econometric models (namely, regression models in price-levels, price first differences, price returns, as well as error correction and autoregressive distributed lag models) in terms of their computed OHR, using monthly data on the JCC over the period January 2000-January 2006. We illustrate and implement a procedure to cross-hedge and price two different swaps on the JCC: a one-month swap and a three-month swap with a variable oil volume. Moreover, we explain how to compute a bid/ask spread and to construct the hedging position for the JCC swap. We then evaluate our swap pricing scheme with backtesting and rolling regression techniques. Our empirical findings show that it is not necessary to use sophisticated econometric techniques, since the price level regression model permits to compute more reliable optimal hedge ratios relative to its competing alternatives. This result is particularly interesting for traders operating in large energy companies, who have exposures on illiquid markets and intend to directly hedge their positions with simple and versatile techniques.

The paper is structured as follows. In Section 2 we present alternative econometric models for proxy hedging illiquid positions. In Section 3 we review some of the most important and recent studies on the estimation of optimal hedge ratios. Section 4 is dedicated to the empirical analysis for pricing and hedging a JCC swap. Specifically, we present the data used in the empirical application; we estimate and compare the different econometric specifications in terms of their ability to compute plausible OHR; we present a procedure to price and hedge two different swaps of the JCC; we evaluate the swap pricing scheme with backtesting and rolling regression techniques. Section 5 concludes.

2 Econometric models

There is no general consensus about the appropriate model that should be used to estimate the optimal hedge ratio (OHR), although, in the last few years, some researchers have proposed studies with a closer look at the statistical properties of the data, such as cointegration and time-varying second moments. In this section we discuss the most popular econometric techniques used in the literature

[1] A popular example of financial products is given by the derivative contracts, which can be considered illiquid when they are scarcely traded.

to estimate the OHRs.

The hedge ratio (HR) is defined as the percentage of the nominal amount of an open position covered by the financial hedging instrument. In particular, we are interested in OHR, that is the HR which minimizes the risk involved in holding a financial asset. When referring to cross-hedging, HR may deviate significantly from 1 and it should be empirically estimated. The optimal commodity hedge ratio β can be computed by minimizing the end-of-period variance of a portfolio composed by two assets: a spot asset ($S(t)$) and the hedge, which is generally a future contract ($F_{T_2}(T_1)$) with an exposure period (T_1) and a maturity period (T_2), $T_2 > T_1$, as described in expression (1):

$$\beta = \frac{cov(S(t), F_{T_2}(T_1))}{var(F_{T_2}(T_1))} \tag{1}$$

We assume that β is constant over to time, although recent studies have dealt with time-varying β (e.g. Moschini and Myers, 2002; Kenourgios et al., 2005).

The relationship between spot and futures prices can be represented with the linear regression model:

$$S(t) = \alpha + \beta F_{T_2}(t) + \epsilon(t) \tag{2}$$

where $t = 1, ..., T$. It is important to notice that equation (2), which is expressed in levels, can be also written in price differences as:

$$S(t) - S(t-1) = \alpha + \beta(F_{T_2}(t) - F_{T_2}(t-1)) + \epsilon(t) \tag{3}$$

or in price returns as:

$$\frac{S(t) - S(t-1)}{S(t-1)} = \alpha + \beta \frac{F_{T_2}(t) - F_{T_2}(t-1)}{F_{T_2}(t-1)} + \epsilon(t) \tag{4}$$

Equation (4) can be approximated by:

$$\ln(S(t)) - \ln(S(t-1)) = \alpha + \beta(\ln(F_{T_2}(t)) - \ln(F_{T_2}(t-1)) + \epsilon(t) \tag{5}$$

Equations (2) and (3) assume a linear relationship between spot and future prices, while equation (4) assumes that the two prices follow a log-linear relation. Relative to equations (2)-(3), HR represents the ratio of the number of units of futures to the number of units of spot that must be hedged, whereas relative to equation (4) HR is the ratio of the value of futures to the value of spot.

Equation (2) is usually estimated with conventional OLS; the estimated β is the OHR given by expression (1), and the regression R-squared (R^2) is used as a measure of the goodness of the hedging. Unfortunately, this specification can easily produce autocorrelated and heteroschedastic residuals (Ederington, 1979; Myers and Thompson, 1989). For this reason, some authors suggest to use equation (3), so that the OLS classical assumption of no correlation in the error terms is not violated (Witt et al., 1987).

Another relevant aspect is data stationarity. It is well known that many economic time serie, such as commodity prices, are non-stationary. However, if the spot price $S_t \equiv S(t)$ and the future price $F_t \equiv F_{T_2}(T_1)$ are integrated of order one (i.e. stationary in first differences) and it is possible to find a linear combination between S_t and F_t that is stationary, the two series are said to be cointegrated. The definition of cointegration was introduced by Engle and Granger (1987), who state that cointegrated variables have an error correction representation (ECM) of the following form:

$$\Delta S_t = \alpha e_{t-1} + \beta \Delta F_t + \sum_{i=1}^{n} \gamma_i \Delta F_{t-i} + \sum_{j=1}^{m} \delta_j \Delta S_{t-j} + u_t \tag{6}$$

where

$$e_{t-1} = S_{t-1} - \alpha F_{t-1} \tag{7}$$

is the error correction term (ECT) measuring the deviation from the long-run equilibrium relationship, $\Delta S_t \equiv \log(S_t/S_{t-1})$ and $\Delta F_t \equiv \log(F_t/F_{t-1})$. In model (6) the presence of lagged variables, ΔF_{t-i} and ΔS_{t-j}, captures short-run dynamics, while β is the OHR.

If second moments are assumed to be time-varying, the OHR has to be estimated accordingly. In this case, GARCH models (see Bollerslev, 1986) are generally employed. The process for a GARCH(p,q) model is defined as follows:

$$\begin{aligned} &\epsilon_t = \vartheta_t \sigma_t \qquad \text{with} \qquad \vartheta_t \; IID(0,1) \\ &\sigma_t^2 = w + \alpha_1 \epsilon_{t-1}^2 + \alpha_2 \epsilon_{t-2}^2 + ... + \alpha_q \epsilon_{t-q}^2 + \beta_1 \sigma_{t-1}^2 + \beta_2 \sigma_{t-2}^2 + \beta_p \sigma_{t-p}^2 \end{aligned} \tag{8}$$

In order to have a positive conditional variance σ_{t-1}^2, the following conditions have to be satisfied:

$$w > 0, \qquad \alpha_i, \beta_j \geq 0, \qquad i = 1, ..., q, \qquad j = 1, ..., p$$

To guarantee a positive conditional variance and to accommodate the so-called leverage effect, we can also consider the exponential GARCH (EGARCH) model introduced by Nelson (1991):

$$\log \sigma_t^2 = w + \beta \log(\sigma_{t-1}^2) + \gamma(\frac{\epsilon_{t-1}}{\sigma_{t-1}}) + \alpha \left| \frac{\epsilon_{t-1}}{\sigma_{t-1}} \right| \tag{9}$$

Another GARCH-type specification is the exponential weighted moving average (EWMA), which is equivalent to the integrated GARCH (IGARCH) model.

Multivariate extentions which have been used in the literature of OHR are the vector autoregressive (VAR) and the vector error correction (VECM) models, which can be specified as:

$$\begin{cases} \Delta S_t = \alpha_s + \sum_{i=1}^K \beta_{si} \Delta S_{t-i} + \sum_{i=1}^K \gamma_{si} \Delta F_{t-i} + u_{st} \\ \Delta F_t = \alpha_f + \sum_{i=1}^K \beta_{fi} \Delta S_{t-i} + \sum_{i=1}^K \gamma_{fi} \Delta F_{t-i} + u_{ft} \end{cases} \tag{10}$$

$$\begin{cases} \Delta S_t = c_s + \sum_{i=1}^K \beta_{si} \Delta S_{t-i} + \sum_{i=1}^K \gamma_{si} \Delta F_{t-i} - \alpha_s e_{t-1} + u_{st} \\ \Delta F_t = c_f + \sum_{i=1}^K \beta_{fi} \Delta S_{t-i} + \sum_{i=1}^K \gamma_{fi} \Delta F_{t-i} - \alpha_f e_{t-1} + u_{ft} \end{cases} \tag{11}$$

A popular multivariate generalisation of the single-equation GARCH model is BEKK (Engle and Kroner, 1995), which ensures the positive definiteness of the conditional covariance matrix by introducing a general quadratic form for the conditional second moments.

3 Review of the existing literature

This section briefly reviews the literature dealing with the estimation of the OHR. The correct approach to hedging is subject to a controversial debate. On the one hand, the strand of OHR literature which is more oriented to finance has focused on the derivate pricing models. On the other hand, that part of OHR literature which is closer to applied economics has stressed the importance of time-series

techniques. Recently, Bryant and Haigh (2005) have compared the two approaches using NYMEX crude oil spot and futures data, concluding that the second techniques produces superior hedging performance.

Our survey examines the studies on cross-hedging, with particular emphasis on the contributions which apply alternative econometric techniques for the estimation of OHR (see Table 1 for a summary of the main characteristics of the reviewed papers).[2]

In 1969 Johnson underlines the importance of future markets for hedging operations. He discusses the theory of hedging, offering a reformulation for commodity markets and constructs a model for hedging and speculation. The theory of cross-hedging has developed in a static framework where future contracts are held without adjustment (Ederington, 1979; Anderson and Danthine, 1981).

It is important to notice that few contributions have been written on cross-hedging commodity prices, and energy commodity prices in particular.

In 2002 Tunaru and Tan examine the exposure to kerosene of an airline company based in an emerging country. The authors try to assess whether it is better to cross-hedge this commodity with a future contract or to transform the problem in cross-hedging the currency, due to the fact that future contracts on kerosene exist only in the Tokyo market. The aim of Tunaru and Tan is to empirically understand if airline companies outside Tokyo are better off using futures in Tokyo and managing currency risk, instead of cross-hedging kerosene with gas oil or heating oil. However, it is important to notice that, in both cases, a basis risk is encountered as a perfect hedging is not possible. They analyse weekly data for the period 4 February 1997 - 21 August 2001, showing that jet fuel is highly correlated to almost all futures traded at IPE and NYMEX. Tunaru and Tan regress equation (2) using OLS on a specification in quasi-differences to account for autocorrelation. Due to some non-synchronization between spot and futures data, the authors apply also the instrumental variables proposed by Scholes-Williams (1977).[3]

Coffey et al. (2000) examine five grain co-products and analyse how to manage price risk, as no future contract exists for these products. In particular, they cross-hedge the five commodities using a price-level model estimated by GLS in order to correct for autocorrelation.

More interesting approaches have been proposed by authors who also concentrate on the comparison between different specifications for OHR. For instance, Witt et al. (1987) discuss whether it is more appropriate to use price levels, price changes or percentage price changes when estimating OHR. They underline the differences in the interpretation of the estimated parameters from the three models, as we have already explained in Section 2. They also use the three procedures proposed on the same dataset in order to estimate OHR and determine which is the best approach. The authors concentrate on the estimation of cross-hedging relationships between barley and sorghum cash prices and nearby corn futures prices for the period 1975-1984. Witt et al. assert that results generated using equation (2) are as robust as the findings obtained using equations (3) and (4). They offer detailed suggestions on how the model to use depends on the type of hedge considered: if the hedge is anticipatory the best model to employ is equation (2), while if the hedge is a storage hedge it is better to implement equation (3).

In 2003 Moosa tests the sensitivity of OHR to model specification using four different models. He

[2] For a more comprehensive review we address the reader to Lien and Tse (2002).

[3] The Scholes-Williams (SW) instrumental variable estimator for the OHR is defined as: $\beta_{SW} = \frac{\hat{cov}(\Delta S(t), IV(t))}{\hat{cov}(\Delta F(t), IV(t))}$, where $IV(t) = \Delta F(t-1) + \Delta F(t) + \Delta F(t+1) = F(t+1) - F(t-2)$.

deals with two sets of data in order to compare equations (2), (3) and (6), with or without lagged variables. The first is a monthly dataset on cash and futures prices of Australian stocks (All Ords index and SPI index), which covers the period January 1987 - December 1997; the second dataset is formed by quarterly observations on spot exchange rates of the UK pound and the Canadian dollar against the US dollar from the first quarter of 1980 to the last quarter of 2004. The author concludes that model specification is not determinant for hedging effectiveness; his results state that correlation between the position to hedge and the instrument used is the most important variable to consider.

Casillo (2004), analysing the index future contract of the Italian derivatives market (FIB30), provides an empirical comparison of four econometric techniques for the estimation of OHR. Although his empirical analysis is applied to a different financial market, the contribution of the author is important in our context, as he underlines advantages and disadvantages of different estimation methods. In particular, he evaluates the hedging performances of equation (3), a bivariate VAR model, a VECM specification, as well as a BEKK model. He assesses that the multivariate GARCH model is marginally better than the others, as it is able to accommodate time-varying OHR.

Some authors account for cointegration of the series using an ECM, while other contributors apply the class of GARCH models assuming that variances and covariances are varying over time. In 1991, Myers proposes two methods for estimating time-varying OHR. The first incorporates time-varying volatility through moving sample variances and covariances of past price prediction errors; the second is a GARCH model as described in equation (8). Referring to wheat prices covering the period January 1977 - May 1983, the author compares the two approaches with the traditional regression method, concluding that the GARCH model performs only marginally better.

Ghosh (1993) proposes an ECM representation to estimate OHR for non-stationarity series. He uses daily data for the period 2 January 1990 - 5 December 1991 on closing prices for the S&P 500 index, Dow Jones Industrial Average, NISE and daily nearby settlement price of S&P 500 index futures contracts. The author compares the out-of-sample forecasting perfomance of equation (3) and ECM. He states that traditional methods (due to misspecification) underestimate OHR and suggests that equation (6) can be useful to hedge foreign currency, commodity and interest rates futures.

In 2002 Moschini and Myers estimate OHR for weekly corn prices using a reformulation of the BEKK model, which allows to test the null hypothesis that OHR is constant over time. Their results show that OHR is time-varying and that its variability cannot be explained by seasonality and time-to-maturity effects.

Harris and Shen (2002) propose an alternative way of estimate OHR in order to account for the leptokurtic distribution of the data. They construct a dynamic hedging strategy for daily returns on the FTSE100 index and apply both a rolling window approach and a EWMA model to estimate robust OHR. They find that the variance of the robust OHR obtained with the EWMA model is 70% lower than the OHR calculated with the rolling window approach.

Ghosh and Bolding (2005) estimate OHR for the Euro market. Using data for the period 2 January 2001 - 7 June 2004 they test for the presence of unit roots, finding that each series is integrated of order 1. They compare the effectiveness of an ECM specification with equation (3), pointing out the superiority of the out-of-sample forecasts based on the first specification.

Kenourgios et al. (2005) apply both a constant and a time-varying model for second moments and investigate the hedging performance of the S&P 500 futures contracts using data for the period July 1992- June 2002. They compare equation (3) with ECM, GARCH and EGARCH models. The authors

find out that ECM generates a larger risk reduction.

4 Pricing and hedging the JCC swap

4.1 Data

The aim of this paper is to cross-hedge and price a swap on the JCC using the econometric models described in Section 2. The dataset consists of monthly observations on the JCC from January 2000 to January 2006. JCC represents the average CIF value of all crude and raw oils imported in Japan in a specific period. Its price is determined as follows:

$$P_{JCC,m} = \frac{V_m}{Q_m} \tag{12}$$

where V_m is the sum of the values of imported crude and raw oils at month m expressed in thousands of Japanes Yen (JPY), and Q_m is the sum of the quantities, expressed in kiloliters, of imported crude and raw oils relative to the m-th month. These data are published monthly and can be downloaded from the web site of the Petroleum Association of Japan (http://www.paj.gr.jp/html/statis/index_e.html), where the JCC series is available also in US dollars (this is actually the series we use in our paper). It has to be noted that, while the European Union does not apply any quantity restrictions to crude oil imports, these imports are duty free, and only finished products are subject to national duties, in Japan crude oil imports are subject to a tariff of 215 JPY/kilolitre. Moreover, Japanese crude oil is mostly imported from the Middle East via tankers. The mechanism used to set the price of a crude oil cargo is country-specific. Most often crude oil is priced on an average of published prices on the Bill of Lading (B/L) date; that is, the price of the B/L date plus or minus a defined number of working days around this date.

The other data we use are the closing prices of the most prompt contract on the futures curve on WTI (WTI1 in Figure 1), which we have aggregated monthly through a simple arithmetic mean, which takes into account that the contract rolls-over on, or around, the 20-th day of each calendar month.

The correlation coefficient between JCC with WTI is, not surprisingly, very high (0.988), as suggested also by Figure 1 which shows a very similar behaviour for the two series.

4.2 Econometric analysis

To illustrate the differences among the alternative econometric specifications for estimating the OHR on the JCC, we analyse the data on JCC and WTI using models (2), (3), (5) and (6). As already discussed in the review section, the literature has proposed several models to estimate the OHR, depending on the statistical properties of the series involved.

The Augmented Dickey Fuller (ADF) test supports the hypothesis that the series are integrated of order 1 and stationary in first differences. Results are reported in Table 2 where the ADF t-statistic is presented for the series in levels and first differences. Table 2 reports also the ADF test on the residual of the Engle-Granger cointegration regression of JCC on WTI, which supports the presence of cointegration between the two variables.

Hedge ratios for the JCC, denoted by β, are reported in Table 3, which also includes the coefficients for the constant term and for the error correction term in model (6). The specification in levels records the highest adjusted R^2, although this model is slightly less statistically adequate than its competitors, as its residuals are affected by autocorrelation and heteroskedasticity, and the model does not exploit the presence of integration and cointegration in the series. Although a direct comparison of the β coefficients across models is not appropriate, as the dependent variable is not the same for each model, nonetheless it is informative to compare the specification in price differences with the model for price returns and with the ECM. Model (6) shows more plausible estimates of the OHR, while specifications (3) and (5) seem to be affected by significant underestimation of the OHR. Furthermore, the ECM model has the highest adjusted R^2 and the error correction term is significant and negative, supporting the convergence of the system to a long-run equilibrium.

In addition to the econometric and statistical implications of the estimated models, it is crucial to fully understand the economic and financial interpretation of the estimated parameters. In this case, in order to hedge a swap on the JCC, the specifications which consider as dependent variable the price difference are not appropriate, rather they only permit to directly price and hedge a swap for the next month. Conversely, when longer hedging periods are considered, several hedge ratios must be estimated according to the specific hedging period, e.g. for a 3-month hedging period the model must consider the third difference of the price. On this last respect, the price-level regression allows to estimate an OHR which can be used regardless the specific swap month, thus providing the trader with a simple and flexible instrument.

In order to better evaluate the empirical performance of the econometric models used to price and hedge the JCC swap, it is important to analyse the time series behaviour of the residuals. The underlying idea is that, if it is not possible to eliminate the serial correlation in the residuals, residual autocorrelation should be priced into the index swap.

Two additional specifications help to improve the statistical adequacy of the price-level regression. The first specification involves the introduction of a moving average (MA) structure, which completely resolves the autocorrelation problem and partially accommodates heteroskedasticity:

$$S(t) = \alpha + \beta F_{T_2}(t) + \epsilon_t, \epsilon_t = u_t + \delta u_t - 1 + \gamma u_t - 2 \tag{13}$$

The second model is the ARDL(1,1) specification:

$$S(t) = \lambda + \alpha F_{T_2}(t) + \delta F_{T_2}(t-1) + \gamma S(t-1) + \epsilon_t \tag{14}$$

where the OHR can be obtained as:

$$\beta = \frac{\alpha + \delta}{1 - \gamma} \tag{15}$$

Expression (15) is strictly related to the OHR estimated with the price-level regression model.
Results for these regressions are summarized in Table 4. Interestingly, both specifications are statistically adequate, and the swap prices calculated on the basis of the two estimated β are very similar.
For an overall comparison of the models applied in our analysis, we present some diagnostic tests on the residuals and a graph with a set of out-of-sample forecasts. Specifically, we calculate the Breusch-Godfrey serial correlation LM test (B-G test), the White heteroskedasticity test (W test) and the Jarque-Bera normality test (J-B test), as well as the standard errors of the regression (S.E.), the number of observations (N.) and the number of parameters (N.p.) (see Table 5). The model in levels is not completely satisfactory from a statistical viewpoint, as residuals present autocorrelation and heteroskedasticity, while the other models do not signal any misspecification. It is worth noticing that the residuals are in general not normally distributed, since the Jarque-Bera tests sistematically reject the joint null hypothesis of zero skewness and zero excess kurtosis.
The out-of-sample analysis is run using the sample period January 2000-January 2005 for estimation and the last year of observations to compare forecasted with actual values. Moreover, an additional forecasting exercise for February, March and April 2006 is also supplied.
Figure 2 is divided into two panels. The first panel compares the observed JCC with the forecast values from the price-level model, the price-differecence model, the price-returns and the ECM. The second panel confronts the actual JCC with the forecast values of the ARDL(1,1) specification and the price level model corrected with MA terms. Both panels also include forecasts for the period February 2006-April 2006. The number associated with JCC refers to the estimated model, e.g. JCC2 refers to the price-level regression represented by model (2).
Models (2), (13) and (14) show more accurate forecasts than their competitors. In other terms, the graphical analysis provided in Figure 2 suggests that the simple price-level model and the price-level model corrected for autocorrelation outperform more complicated econometric specifications.

4.3 Swap pricing and hedging

A swap, also known as fixed-for-floating contract, is an agreement between two parts which defines the exchange of a floating energy price for a fixed energy price. In energy markets, this agreement can be set up as a contract for differences (CDF), meaning that there is no exchange of a floating versus a fixed, but only the settlement of a difference. The CDF contract defines the fixed volume or quantity over a specified period of time, and it is usually settled for a particular frequency: monthly, quarterly, semi-annual or annual.
A commodity swap can be seen as a strip of forward contracts, thus the payoff at each reset date is equal to the payoff of the forward contract. Therefore, the value of the swap can be written as a weighted average of the underlying forwards.
In this section we consider two examples in order to illustrate the mechanisms we propose to price and hedge a swap on the JCC. The first example is represented by a one-month (1M) swap on the

JCC index in October 2006, with a notional volume of oil V_{oct06}. The swap payoff at cash settlement is therefore:

$$P(swap) = V_{oct06}(K - P_{oct06}(JCC)) \tag{16}$$

where K is the corresponding fixed price and $P_{oct06}(JCC)$ is the price of JCC index in October 2006. The price of the swap on the JCC index for October 2006 will be calculated as follows: β estimated using one of the econometric models discussed in the previous section, multiplied by the price of the WTI futures contract which delivers in October 2006 (WTI_{oct06}), plus the estimated constant term:

$$Price(swap) = \hat{\beta} WTI_{oct06} + c \tag{17}$$

Specifically, the rationale behind expression (17) is that the price represents the cost of hedging this position. The error terms of the underlying regression model measure the basis risk, while the constant term captures that part of the swap price that the WTI is not able to explain.
With a simple backtesting procedure (see Section 4.4 for details), it is possible to calculate the maximum absolute value of ϵ, i.e. the difference between the estimated swap price in equation (17), and the actual value of the JCC index. We then define a bid/ask spread, which allows us to offset the remaining risk and whose size is actually given by the maximum value of the recorded errors ϵ:

$$\begin{cases} Price_{bid} = Price(swap) - \max|\epsilon| \\ Price_{ask} = Price(swap) + \max|\epsilon| \end{cases} \tag{18}$$

The dimension of the bid/ask spread is directly proportional to the risk aversion of the price maker. With this respect, the bid/ask spread proposed by expression (18) would be considered a conservative swap pricing criterion, coherent with a highly risk-adverse behaviour. Conversely, in a competitive market a price maker will probably set a smaller bid/ask spread.
In any case, it is reasonable to price the bid/ask spread of the swap according to the empirical distribution of ϵ in expression (18). If ϵ is normally distributed, we can use the symmetric tails of the normal distribution to build up the price. Alternatively, should the hypothesis of normality be rejected, we can consider a given percentile of the empirical distribution of ϵ, which depends on the trader's risk preferences. For instance, assuming that expected profits are positive 95 percent of the times, we can construct the swap price by adding and subtracting in expression (18) the 95-th percentile of the distribution of ϵ, instead of its maximum value.
The hedging position will consist on selling [4] an amount of WTI futures contracts delivering at October 2006. In order to close the financial position it will be necessary to buy $(1/n)\beta$ units of the future contract in each single day of the considered month (i.e. October 2006 in our example), where n is the number of trading days in the month with respect to which the JCC will be calculated. According to this procedure, at the end of the month we will have no position on future contracts, whereas our balance will be the sum of the difference paid and received during the life of the future contract, plus and minus the difference between the selling price and the buying price.[5]

[4] This is due to the fact that the correlation is positive and we receive the fixed price. [5] This analysis does not take into account the time value of the money and the future/forward convexity adjustment problem.

The second example considers a swap price on the JCC index for the fourth quarter of 2006, with a variable oil volume profile for the m-th month, V_m. Ignoring the time value of money, the payoff for this swap is:

$$P(swap) = \sum_{m=1}^{3} V_m(K_m - P_m(JCC)) \tag{19}$$

The choice of a simple and versatile model for estimating β, such as models (2) and (14), significantly simplifies the procedure to price and hedge this kind of swap, since the same OHR can be applied for each of the three months of the fourth quarter of 2006. In this context, the price of the swap is the average of the prices for the three months, taking into account the variable volume:

$$Price(swap) = \frac{1}{3}\sum_{m=1}^{3} V_m\hat{\beta}WTI_m + c \tag{20}$$

The bid/ask spread is constructed according to equation (18), after running a single backtest for each month and averaging out the results. This bid/ask spread could be reduced by exploiting the correlation among the errors in the various months. Alternatively, the formulation proposed in this paper seems to be more protective. In our framework, the final price for the swap is:

$$\begin{cases} Price_{bid} = Price(swap) - \frac{1}{n}\sum_{i=1}^{n} \max|\epsilon_i| \\ Price_{ask} = Price(swap) + \frac{1}{n}\sum_{i=1}^{n} \max|\epsilon_i| \end{cases} \tag{21}$$

where n=3. The hedging position to be taken is to sell the correct amount of WTI futures contracts delivering in each of the three months according to the variable volume. The financial position will be closed for each month in the same way as described for the one-moth swap.

4.4 Evaluating the swap pricing scheme: backtest and rolling regressions

In order to empirically test the pricing mechanism we proposed in the previous section, we run a backtest for the two most appropriate econometric specifications, namely the simple price-level model and the ARDL.

The backtest has been performed for the whole sample, under the assumption that the swap to price is a one-month swap. Data availability (that is, WTI future prices from month 1 to month 4) permits to backtest the price of the swap for each of the next four months.

Our backtest procedure consists of multiplying the β coefficient reported in Tables 3 and 4 for the WTI price and to add the estimated constant term. In this way, for each day of the sample we are able to obtain an average price for four swaps and compare this fitted price with the actual JCC index for that month.

A parsimonious and informative approach for evaluating the series of swap prices is to compare the minimum and the maximum values computed as the difference between the estimated swap price and

the actual JCC index, since ideally this difference should be equal to zero. Table 6 presents the maximum and the minimum values of the errors, as well as the associated standard deviation. Although the reported error values are different from zero at conventional significance levels, nevertheless it emerges that the swap price for the first month registers the highest positive error (+16.50) when priced with the ARDL model, while the lowest negative error (−8.72) is recorded if estimated with the price-level model. Moreover, with both econometric models positive errors decrease as the reference month for the swap increases. In general, the price-level model seems to (slightly) outperform the ARDL specification. The maximum value of the errors which is closer to zero is recorded by the price-level model for a 4 month-swap (i.e. 13.19 for the price-level model versus 13.40 of the ARDL), whereas the minimum error value which is closer to zero is produced again by the price-level model for a 3 month-swap (i.e. −8.72 for the price-level model versus −9.12 of the ARDL).

It is also of capital importance to understand if the estimation procedure is robust to the choice of the sample period. For this purpose, we have re-estimated models (2) and (14) with a 24-month-window rolling regression.

The maximum value for the β estimated with the price-level model is 0.893, the minimum value is 0.676, whereas the average value, out of 48 regressions, is 0.800. The constant term associated with the maximum estimated β takes, for the same model, a maximum value of 8.83 and a minimum of 1.26, with an average value of 4.61. Moreover, the maximum and minimum values associated with the β estimated with the ARDL model are 0.926 and 0.257 respectively, with an average of 0.784; the estimated constant term is within the interval (5.672, −0.993), with an average value of 2.594. Overall, the price-level model seems to be less sensitive to sample selection.

A further investigation of the stability issue is carried out by running a backtest on the rolling regression results. This backtest is calculated for each model and for each swap, using the maximum and the minimum estimated β and the associated constant term (see Table 7). As before, the differences between the actual JCC and the estimated swap price are in general statistically significant. Contrary to the previous case, however, the empirical findings are more mixed, although in general they are favourable to the price-level model. When the maximum error values are considered (see second column of Table 7), model (14) outperforms model (2) for the 4-month swap in correspondence of the maximum value of the estimated β (maximum error values are 12.38 and 13.28, respectively), while for the minimum β values the empirical performance of the 4-month swap based on the price-level model is better than the corresponding swap calculated on the ARDL specification (maximum error values are 16.62 and 44.38, respectively). If we concentrate on the minimum error values (see third column of Table 7), model (2) is always preferable to model (14). In particular, the error of the 3-month swap based on model (2) for the maximum value of β is closer to zero than the corresponding error calculated with the ARDL model (i.e. −8.96 versus −10.47). Finally, the error of the 4-month swap based on the price-level model is closer to zero than the corresponding error of the 2- and 3-month swap computed with the ARDL specification.

5 Conclusions

In this paper we have explained and analysed the risk associated to illiquid financial products. The main contribution of this paper is the presentation of a simple econometric strategy for pricing and

hedging illiquid products, such as the Japanese crude oil cocktail (JCC) index, the most popular OTC energy derivative in Japan. We have reviewed the existing literature for computing optimal hedge ratios (OHR) and we have proposed a critical classification of the existing approaches. We have compared the empirical performance of different econometric models (namely, regression models in price-levels, price first differences, price returns, as well as error correction and autoregressive distributed lag models) in terms of their computed OHR, using monthly data on the JCC over the period Janury 2000-January 2006. We have illustrated and implemented a procedure to cross-hedge and price two different swaps on the JCC: a one-month swap and a three-month swap with a variable oil volume. Moreover, we have explained how to compute a bid/ask spread and to construct the hedging position for the JCC swap.

A parsimonious and informative approach for evaluating the series of swap prices is to compare the minimum and the maximum values computed as the difference between the estimated swap price and the actual JCC index, since ideally this difference should be equal to zero. Although the reported error values are different from zero at conventional significance levels, nevertheless our empirical findings have shown that the swap price for the first month registers the highest positive error when priced with the ARDL model, while the lowest negative error is recorded if estimated with the price-level model. With both econometric models positive errors decrease as the reference month for the swap increases. In general, the price-level model seems to (slightly) outperform the ARDL specification. The maximum value of the errors which is closer to zero is recorded by the price-level model for a 4 month-swap, whereas the minimum error value which is closer to zero is produced again by the price-level model for a 3 month-swap.

Then, we have evaluated our swap pricing scheme with backtesting and rolling regression techniques. Since it is important to understand if the estimation procedure is robust to the choice of the sample period, we have re-estimated the price-level and the ARDL models with a rolling regression technique. A further investigation of the stability issue is carried out by running a backtest on the rolling regression results. This backtest is calculated for each model and for each swap, using the maximum and the minimum estimated OHR and the associated constant term. Contrary to the previous case, the empirical findings are more mixed, although in general they are favourable to price-level model. When the maximum error values are considered, the ARDL model outperforms the price-level model for the 4-month swap in correspondence of the maximum value of the estimated OHR, while for the minimum OHR values the empirical performance of the 4-month swap based on the price-level model is better than the corresponding swap calculated on the ARDL specification. If we concentrate on the minimum error values, the price-level model is always preferable to ARDL. In particular, the error of the 3-month swap based on the price-level model for the maximum value of OHR is closer to zero than the corresponding error calculated with the ARDL model; the error of the 4-month swap based on the price-level model is closer to zero than the corresponding error of the 2- and 3-month swap computed with the ARDL specification.

Overall, our empirical findings have shown that it is not necessary to use sophisticated econometric techniques, since the price level regression model permits to compute more reliable optimal hedge ratio relative to its competing alternatives. This result is particularly interesting for traders operating in large energy companies, who have exposures on illiquid markets and intend to directly hedge their positions with simple and versatile techniques.

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Table 1: Summary of the surveyed literature

Year	Authors	Model	Data	Time period	Frequency
1987	Witt et al.	(2), (3),(4)	Barley and sorghum cash prices, nearby corn future prices	1975-1984	weekly
1991	Myers	(3), (8)	wheat prices	6/1977-5/1983	weekly
1993	Gosh	(3), (6)	Closing price for the S&P 500 index, Dow Jones Industrial Average, New York Stock Exchange composite index and daily nearby settlement price of S&P 500 index future contracts	2/1/1990-5/12/1991	daily
2000	Coffey et al.	(2)	Five grain co-products	1981-1998	weekly
2002	Moschini and Myers	BEKK	Corn prices	1/1976-6/1997	weekly
2002	Tunaru and Tan	(2)	Kerosene price and crude oil futures traded at IPE and NYMEX, heating oil (NYMEX),unleaded regular gas (NYMEX),liquid propane gas (NYMEX)	4/2/1997-2178/2001	weekly
2002	Harris and Shen	EWMA	FTSE100 index	4/5/1985-3/5/2002	daily
2003	Moosa	(2), (3),(6)	Cash and futures prices of Australian stocks (All Ords index and SPI index)	1/1987 - 12/1997	monthly
			Spot exchange rates of the UK pound and the Canadian dollar against US dollar	1/1980-4/2004	quarterly
2004	Casillo	(3), (10), (11), BEKK	MIB30 index and FIB30	28/11/1994-10/6/2004	daily
2005	Gosh and Bolding	(3),(6)	Euro spot and futures traded on the Chicago Mercantile Exchange	2/1/2001-7/6/2004	daily
2005	Kenourgios et al.	(3),(6), (8),(9)	S&P 500 future contract	7/1992-6/2002	weekly

Table 2: Augmented Dickey-Fuller unit root tests

	JCC	WTI	Coint. residuals
ADF (series in level)	0.709	0.292	-4.008**
ADF (series in first differences)	-6.787**	-7.766**	-

Notes: *(**) indicates rejection of the null hypothesis of a unit root at 10%(5%) significance level; Coint. residuals = residuals from the cointegrating regression of JCC on WTI.

Table 3: Estimated optimal hedge ratios (January 2000 - January 2006)

	Model (2)	Model (3)	Model (5)	Model (6)
β	0.876** (0.016)	0.589** (0.052)	0.641** (0.055)	0.718** (0.061)
constant	2.193** (0.598)	0.156 (0.140)	0.003 (0.004)	0.002 (0.004)
ECT(-1)	-	-	-	-0.275** (0.109)
Adj.R^2	0.976	0.641	0.653	0.677

Notes: *(**) indicates that the corresponding coefficient is statistically significant at 10%(5%); standar errors are reported in parentheses.

Table 4: Estimation results for optimal hedge ratio (January 2000 - January 2006)

	Model (13)	Model (14)
β	0.855** (0.025)	0.909**(0.067)
constant	2.978** (0.919)	0.326 (0.499)
MA(1)	0.662**(0.117)	-
MA(2)	0.318**(0.117)	-
Adj.R^2	0.984	0.987

Notes: *(**) indicates that the corresponding coefficient is statistically significant at 10%(5%); standar errors are reported in parentheses.

Table 5: Diagnostic tests for model residuals

	Model (2)	Model (3)	Model (5)	Model (6)	Model (13)	Model (14)
B-G test	28.17(0.000)	0.382(0.825)	0.140(0.932)	1.540(0.463)	3.014(0.221)	1.677(0.432)
J-B test	65.76(0.000)	35.02(0.000)	112.98(0.000)	117.01(0.000	31.07(0.000)	45.94(0.000)
W test	11.69(0.003)	1.864(0.393)	1.360(0.035)	1.440(0.837)	6.505(0.038)	8.985(0.174)
S.E.	1.590	1.175	0.035	0.034	1.266	1.153
N.	73	72	72	72	73	72
N. p.	2	2	2	3	4	4

Notes: p-values are reported in parentheses.

Table 6: Backtests for model (2) (price-level) and model (14) (ARDL)

Model	Maximum	Minimum	Standard deviation	N. obs.
Model (2) (1-month)	16.17	-9.42	4.27	1184
Model (2) (2-month)	14.55	-9.06	4.04	1184
Model (2) (3-month)	13.68	-8.72	3.94	1184
Model (2) (4-month)	13.19	-8.80	3.89	1184
Model (14) (1-month)	16.50	-9.37	4.29	1184
Model (14) (2-month)	14.82	-9.12	4.07	1184
Model (14) (3-month)	13.92	-9.15	3.98	1184
Model (14) (4-month)	13.40	-9.23	3.94	1184

Notes: Maximum = maximum value of the difference between the model-based swap price and the actual JCC price; Minimum = minimum value of the difference between the model-based swap price and the actual JCC price.

Table 7: Backtests for model (2) (price-level) and model (14) (ARDL) (rolling regressions)

Model	Maximum	Minimum	Standard deviation	N. obs.
Model (2) (Max β, 1-month)	16.33	-9.42	4.27	1184
Model (2) (Max β, 2-month)	14.67	-9.06	4.05	1184
Model (2) (Max β, 3-month)	13.78	-8.96	3.96	1184
Model (2) (Max β, 4-month)	13.28	-9.04	3.91	1184
Model (2) (Min β, 1-month)	18.93	-9.01	4.88	1184
Model (2) (Min β, 2-month)	17.68	-9.25	4.65	1184
Model (2) (Min β, 3-month)	17.00	-9.22	4.53	1184
Model (2) (Min β, 4-month)	16.62	-8.96	4.45	1184
Model (14) (Max β, 1-month)	15.54	-10.48	4.31	1184
Model (14) (Max β, 2-month)	13.82	-10.47	4.10	1184
Model (14) (Max β, 3-month)	12.90	-10.51	4.02	1184
Model (14) (Max β, 4-month)	12.38	-10.59	3.98	1184
Model (14) (Min β, 1-month)	45.26	9.79	8.38	1184
Model (14) (Min β, 2-month)	44.78	9.70	8.29	1184
Model (14) (Min β, 3-month)	44.52	9.70	8.24	1184
Model (14) (Min β, 4-month)	44.38	9.81	8.20	1184

Notes: Maximum = maximum value of the difference between the model-based swap price and the actual JCC price; Minimum = minimum value of the difference between the model-based swap price and the actual JCC price; Model (i) (Max β, j-month) = error based on model (i) (i=2,14), for the j-month swap (j=1,...,4), calculated in correspondence of the maximum value of the estimated β; Model (i) (Min β, j-month) = error based on model (i) (i=2,14), for the j-month swap (j=1,...,4), calculated in correspondence of the minimum value of the estimated β.

Figure 1: JCC and WTI (January 2000 - January 2006)

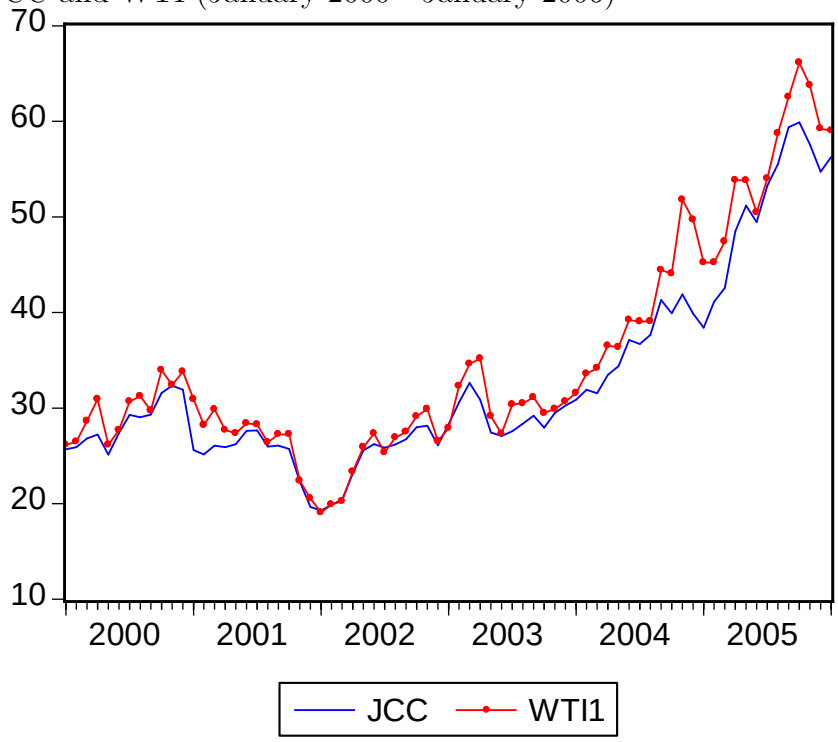
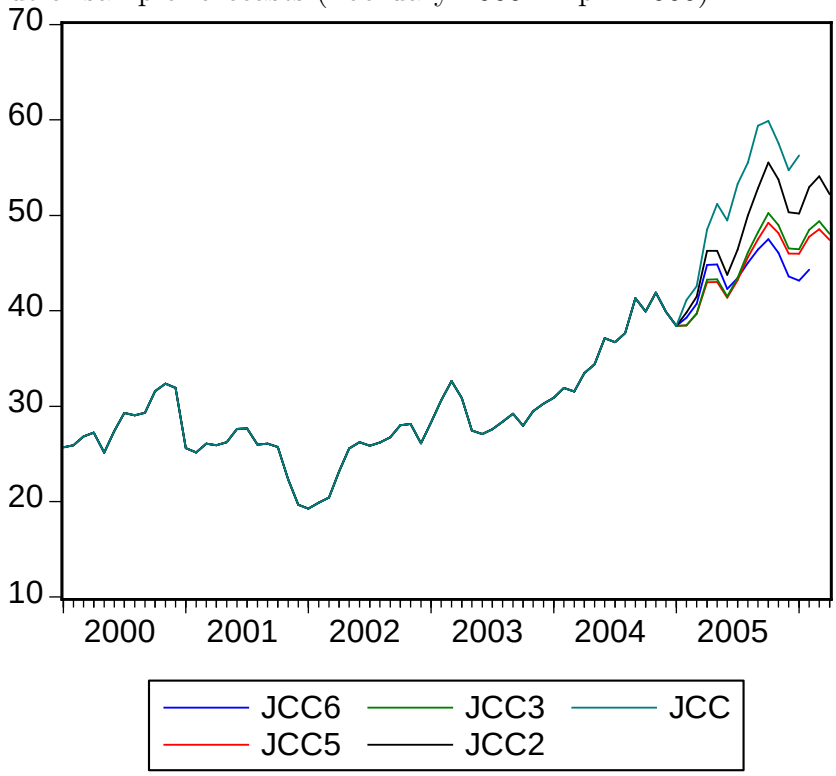
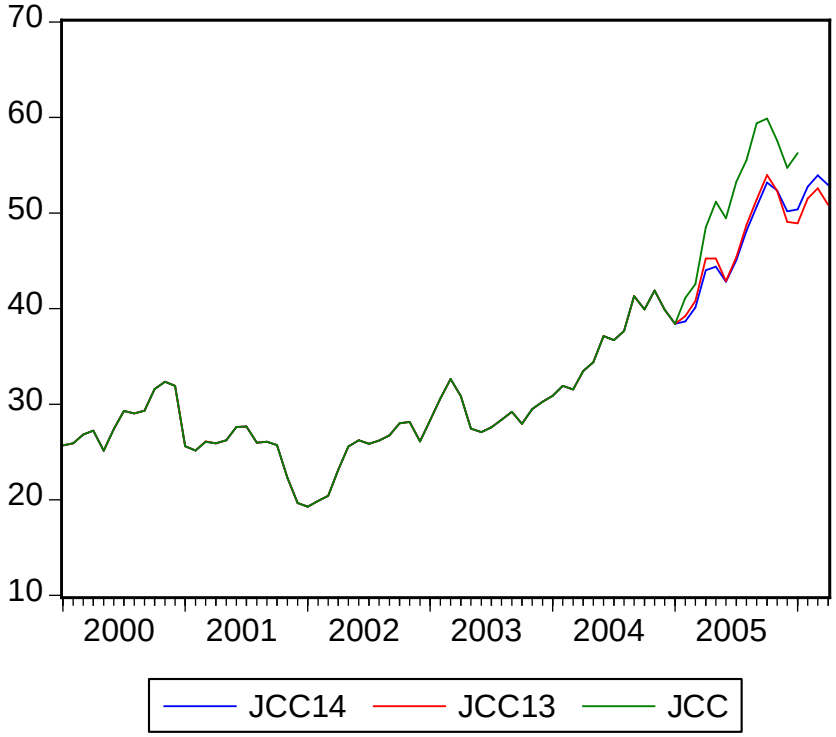


Figure 2: Out-of-sample forecasts (February 2005 - April 2006)





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