Futures Price Dynamics of CO₂ Emission Allowances – An Empirical Analysis of the Trial Period

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Abstract

CO$_2$ emission allowances are traded with increasing liquidity within the EU emissions trading scheme. Besides spot contracts, futures and options are also available OTC and on exchanges across Europe. The focus of this study is on the relationship between spot and futures markets in the EU ETS. An empirical examination reveals that after initial divergence spot prices equal discounted futures prices for futures maturing within the trial period. Moreover, we find that these futures contracts lead the price discovery process of CO$_2$ emission allowances. EUA futures can therefore be of crucial importance for all participants in the emission market through facilitating price discovery and offering means of hedging CO$_2$-related risks. However, due to the market design, we are not able to learn much about fair second period futures prices from the current spot market.

JEL Classification: G13, Q50

Keywords: CO$_2$ emission allowances, CO$_2$ futures, cash and carry
1 Introduction

The EU emissions trading scheme (EU ETS) dominates the global carbon market with spot, futures, and option trades in market value of US$50 billion (€37 billion) in 2007. Futures contracts account for the major part of this value.\(^1\) Understanding the relationship between spot and futures prices is thus of crucial importance for all participants in the carbon market. Naturally, this relationship depends on the underlying market characteristics. Greenhouse gas emission rights, called EU allowances (EUAs), allow for the emission of one ton of CO\(_2\) each. At present, the EU ETS comprises two trading periods, the trial period from 2005 - 2007 and the so-called Kyoto commitment period from 2008 - 2012. A proposal for the third trading period from 2013 onwards is currently discussed. Within these trading periods, not only regulated CO\(_2\) emitters but any investor may trade EUAs without restriction. As storage of EUAs is possible and virtually costless within trading periods, a long forward position can easily be replicated by buying EUAs on credit. If, on the other hand, there is no direct benefit of possessing EUAs until needed for compliance, regulated CO\(_2\) emitters could sell some of their EUAs and use a money market account to replicate a short forward position. In this case, the relationship between spot and forward prices should be described entirely by the cost-of-carry approach.

Although there is some recent research examining the price dynamics of EUAs,\(^2\) only very few papers analyze how EUA spot and futures prices are related. Daskalakis/Psychoyios/Markellos (2009) use a jump-diffusion spot price model and a mean reversion stochastic convenience yield to describe the relationship between spot and futures markets for contracts written within the trial period that expire in the Kyoto commitment period.\(^3\) In contrast to this work, our main focus is on futures contracts that are written and maturing in the same period.\(^4\) We thoroughly analyze the relationship between spot and first period futures contracts in order to provide empirical evidence for or against the cost-of-carry relation. Moreover, we argue that due to the market design there is no clear

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1 See Capoor/Ambrosi (2008).
3 See also Borak et al. (2006) who analyze convenience yields for futures prices with maturities up to 2012.
4 To verify that the standard cost-of-carry relationship holds for first period futures, Daskalakis/Psychoyios/Markellos (2009) simply calculate mean squared deviations between theoretical and actual futures prices and argue that these confirm our findings for first period futures contracts.
connection between spot and second period futures prices because futures for the second trading period are written on an underlying that is not actually being traded in the first period. EUAs for the trial period cannot be used for compliance in the Kyoto commitment period. Therefore, at least from an economic perspective, it is not very instructive to define a convenience yield in a backwards manner, such that the usual no-arbitrage pricing relationship holds. One should simply state that in this case, we are not able to learn much about fair futures prices from the current spot market.

In the following Section 2, we introduce the institutional details that are relevant for our analysis. Section 3 discusses the relationship between spot and futures prices taking into account the underlying market characteristics. Within a trading period, we expect the cost-of-carry approach to be valid, whereas no clear relationship is expected to exist between spot and futures contracts maturing in the next trading period due to strict banking and borrowing constraints. Section 4 performs empirical tests based on the cointegration methodology and analyzes whether spot or futures prices lead the price discovery process. First, we test whether spot and futures prices follow the cost-of-carry approach in the long-term. Before December 2005, there existed apparent arbitrage possibilities in the immature market. Thereafter, a fairly stable cointegrating relationship emerged between spot and futures prices in accordance with the cost-of-carry approach. We thus also continue to analyze the short-term dynamics within a suitable vector error correction model (VECM). Due to the immaturity of the EU ETS, deviations from the equilibrium relationship may have existed for some time. However, our estimates indicate that the equilibrium is restored within only a few days. The VECM also allows to study whether the futures market serves as a price discovery vehicle for the spot prices, giving an indication of which market processes information more efficiently. Section 5 concludes.

2 The EU Emissions Trading Scheme

The EU-wide emissions trading scheme started in 2005. It was introduced on the basis of the Kyoto Protocol, an international agreement adopted in 1997 with the aim of reducing global greenhouse gas emissions caused by humankind.\textsuperscript{5} The Kyoto Protocol therefore

\textsuperscript{5} See United Nations (1998).
defines emission caps for industrialized and transition countries. These caps are valid for the first Kyoto commitment period from 2008 - 2012. To facilitate the reduction of greenhouse gases, the Kyoto Protocol includes three flexible mechanisms, which are the clean development mechanism (CDM), joint implementation (JI), and international emissions trading (IET). While JI allows industrialized or transition countries to jointly invest in emission reduction projects in other industrialized or transition countries, the CDM allows industrialized or transition countries to invest in emission reduction projects in developing countries. For emission reductions resulting from JI and CDM projects, countries are granted *Emission Reduction Units* (ERU) and *Certified Emission Reductions* (CER), respectively. Countries may use ERUs and CERs to comply with their emission caps. IET allows for emissions trading between governments.

The EU member states implemented the emissions trading scheme in order to jointly reach their Kyoto goals in a cost-efficient way.\(^6\) While IET allows for emissions trading between governments on the basis of the Kyoto Protocol, the EU ETS breaks down the emissions trading to the company level. The EU ETS comprises combustion installations exceeding 20 MW, refineries, and coke ovens as well as the metal, pulp and paper, glass, and ceramic industries. Each year at the end of February, companies with any of these installations are allocated a certain number of EUAs. One EUA allows for the emission of one ton of CO\(_2\) in the current calendar year. On April 30\(^{th}\) of the following year, companies have to submit EUAs to the national surveillance authorities according to their actual emission volumes. If projected emissions exceed their allocated EUAs, companies have two possibilities to solve the problem. They may either abate some of their emissions or buy the EUAs they lack on the market. The intended effect is that companies with cheap abatement opportunities will abate more CO\(_2\) and sell the EUAs in the market to companies for which abatement is more costly. If companies fail to comply, they have to pay a penalty and must also deliver the missing EUAs in the following year. EUAs are freely tradable across all EU member states, meaning that companies may also buy EUAs from companies in other countries.

However, there is a major restriction, commonly referred to as the trading period break. EUAs that are issued in the first trading period (2005 - 2007) are only valid during this trading period. They may not be used for the second trading period, the Kyoto

commitment period (2008 - 2012). The act of storing an EUA for later usage is commonly called banking. Only France and Poland initially allowed limited banking between 2007 and 2008, but later decided to ban inter-period transfer as did all other member states.\(^7\) The opposite approach – borrowing an EUA from a future year – is also possible within a trading period. As companies obtain their EUAs for the current year at the end of February, they may already use these EUAs to comply with the preceding year, as the compliance date can be as late as April 30\(^{th}\). However, this is not possible between 2007 and 2008. As a result, there are essentially two markets, one for the first trading period (2005 - 2007) and one for the second trading period (2008 - 2012).

### 3 Spot versus Futures Prices

#### 3.1 SPOT PRICES, FUTURES PRICES, AND MARKET CHARACTERISTICS

The relationship between spot and futures prices depends on the underlying market characteristics. As Ross (1997) points out, there exists a whole spectrum of markets. At the one end there are commodities such as gold, which behave like investment assets and can easily be stored. The futures price is then determined by no-arbitrage conditions. If we assume for the moment a constant interest rate \( r \) and no storage costs or dividends, then the only costs of holding the underlying are the foregone interests. It therefore follows the standard cost-of-carry relation

\[
TF_t(T) = e^{rt}S_t,
\]

with \( S_t \) denoting the spot price at time \( t \) while \( TF_t(T) \) stands for the futures price of a contract with delivery in \( T \). However, in many commodity markets, a significant part of the demand is driven by real needs. As a consequence, holding the physical commodity not only imposes costs but may also result in an additional benefit for the holder. According to Brennan (1991), this benefit, which accrues to the owner of the spot commodity as opposed to the owner of a futures contract, is defined as a convenience yield. Such benefits may arise through the opportunity to circumvent shortages in the spot market.

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\(^7\) Companies may also use CERs and ERUs generated from CDM and JI projects for compliance instead of EUAs. CERs are bankable from the first to the second trading period, but there is a strict percentage limit for their usage in the EU ETS.
commodity when needed for a production process. Typical examples are fuels like gas, coal, and oil. If we assume a constant flow of benefits the convenience yield approach is thus given by

\[ TF_t(T) = e^{(r-c)(T-t)} S_t. \]

Here \( c \) describes the constant convenience yield net of physical storage costs. It is sometimes argued that the convenience yield shows a correlation to some exogenously given variables. An example for such a correlated variable is the total stock of inventory for the corresponding commodity. In this case, the convenience yield itself may be stochastic and will weaken the link between spot and futures prices.

Finally, at the other end of the market spectrum, there exist pure consumption goods, which are either virtually unstorable or are storable only at prohibitive costs, such as power or wheat. In this situation, there is no longer a clear connection between spot prices and futures prices. A definition of a convenience yield in a backwards manner, such that the usual no-arbitrage pricing relationship holds, might be useful from a modeling perspective. However, the economic meaning would no longer correspond to Brennan's definition of the flow of services that accrues to the investor from holding an inventory. In this case, we are not able to learn much about fair futures prices from the current spot market. It is thus necessary to build expectations vis-à-vis the future spot prices in order to price futures contracts.

As explained above, EUAs are tradable without restrictions within trading periods, and the only significant storage costs are the foregone interests. The only plausible reason for discounted futures prices to differ from spot prices in the absence of stochastic interest rates is thus a potential convenience yield of the spot EUA.

Is there a positive effect of possessing EUAs as opposed to holding a futures position capable of creating a positive convenience yield? Spot EUAs are only needed once a year to fulfill compliance requirements. Thus, if futures mature before the end of the next compliance date, there is no benefit of holding spot EUAs as opposed to holding the corresponding long futures position. If, on the other hand, futures mature after the next compliance date, the futures position has the disadvantage of not being usable for compliance purposes before delivery. However, companies may borrow EUAs from the future year if they run short of EUAs. Thus, there is a real constraint only if a company's
position in futures maturing after the next compliance date is larger than its ability to borrow EUAs from the future year. This scenario is best described as a short-selling constraint in the magnitude of the yearly EUA allocation. A second reason for a positive convenience yield may be that companies unacquainted with capital market business do not trust in the reliable delivery of maturing futures contracts. When we disregard the second reason the convenience yield of EUAs is negligible from an economic point of view for futures maturing before the end of the next compliance date because such futures contracts are converted into spot positions prior to the compliance date. Since companies can easily borrow EUAs from next year’s allocation we also do not expect a significant convenience yield for futures maturing after the next compliance date but still within the same trading period.

In general, forward and futures prices differ due to marking-to-market and implied options. Since the futures on EUAs do not include valuable options, such as those regarding the quality of the underlying to be delivered, only the valuation differences due to marking-to-market effects stemming from correlations between the EUA spot prices and the risk-free interest rates remain. However, the evidence for such a correlation is weak. Thus, for the purpose of this study, we neglect the difference and treat forwards and futures equivalently. The relationship between spot and futures prices within a trading period should thus be explained entirely by the cost-of-carry approach as described in equation (3.1).

From the point of view of the trial period, futures maturing in the second trading period constitute a different situation. The first period spot certificate may not be transferred to the second trading period. For a future 2008, for example, the situation is thus comparable to the situation described above for power and wheat. The cash-and-carry arbitrage is not possible and the current (first period) spot certificate is of no use for the second trading period. Moreover, the expected spot price for the year 2008 is influenced by factors that do not have any impact on first period’s spot prices, such as the final decision of the EU vis-à-vis EUA allocations for the second trading period. As a consequence, we do not expect the cost-of-carry or constant convenience yield approach to hold in this situation.

8 We perform a short correlation analysis of changes in EUA spot prices from the Powernext exchange and changes in the interest rates relevant for the futures contract maturing in December 2006. The time period coincides with our sample period from June 2005 to November 2006. Although statistically significant, the correlation coefficient is as low as -0.16.
Equation (3.1) allows us to calculate theoretical futures prices from spot prices and interest rates and compare them to observed futures prices. Comparing observed and theoretical futures prices has the advantage of ensuring that the theoretical cointegration relationship remains constant over time. Accordingly, we define the difference between observed and theoretical futures prices as equilibrium error $v_t$,

\begin{equation}
 v_t = F_t(T) - TF_t(T) = F_t(T) - e^{r(T-t)}S_t.
\end{equation}

The analysis of these price differences tells us whether our pricing assumption (3.1) for futures contracts is valid. However, it does not explicitly test whether a convenience yield exists. For this, we calculate implied yields by

\begin{equation}
 y_t(T) = \frac{1}{T-t} \ln \left[ \frac{F_t(T)}{S_t} \right],
\end{equation}

where $y_t(T)$ describes the yield between times $t$ and $T$ implied from spot and observed futures prices $F_t(T)$. According to equation (3.1), this implied yield should equal the risk-free interest rate for the relevant time period. Thus, we define the difference between implied yields and riskless interest rates as equilibrium error $\omega_t$,

\begin{equation}
 \omega_t = y_t(T) - r = \frac{1}{T-t} \ln \left[ \frac{F_t(T)}{S_t} \right] - r.
\end{equation}

Any difference of $y_t(T)$ and $r$ can be attributed to a possible convenience yield.

3.2 DATA DESCRIPTION

Both spot EUAs and futures contracts are traded on several exchanges across Europe. We choose to work with spot prices from the Powernext exchange\(^9\) and futures prices from the European Climate Exchange (ECX) for two reasons. First, volume data from Bloomberg showed that the Powernext was the most liquid EUA spot exchange, while the ECX was the most liquid futures exchange for EUAs in the trial period. Second, in June 2005, the Powernext and the ECX announced plans to merge their operations in order to

\(^9\) Competition for market share of the global carbon market induced several announcements about alliances between exchanges and the launch of new exchanges. Powernext® Carbon, the leading spot EUA market, was sold to NYSE Euronext in December 2007 and NYSE Euronext launched the new environmental exchange BlueNext.
offer both spot and futures trading for EUAs from the same screen. Our data sample comprises daily settlement prices from 24/06/2005 - 15/11/2006.

In the following, we compare spot prices with futures prices maturing in December 2006 and December 2007. In order to show the effects of the trading period break at the end of 2007, we include future 2008 prices to our analysis. Regarding interest rates, we use EURIBOR mid-quotes for maturities up to one year and EuroSwap mid-quotes for maturities above one year. Table 1 explains the abbreviations for all the time series used to analyze the pricing relationships and shows some descriptive statistics. In addition, Table 2 shows descriptive statistics of the corresponding equilibrium errors $v_t$ and $\omega_t$.

Figure 1 provides a first impression by showing theoretical future 2006 prices calculated with equation (3.1) from spot prices and interest rates along with observed future 2006 prices (F06/TF06). While a small difference between the two lines is noticeable at the beginning, in the second half of the observed time period, it is hard to see the difference at all. Figure 2 shows observed and theoretical future 2008 prices (F08/TF08). As expected, we see a completely different picture. During the first half of the sample period, the theoretical futures price is clearly above the observed futures price. This would imply a positive and strongly fluctuating convenience yield. However, in the second half of the sample period, the situation seems reversed, now implying a large and fluctuating negative convenience yield. This supports our view that it is not suitable to think in terms of constant or economically meaningful convenience yields. The closer the year 2008 approaches, the more information about the second trading period's allocations becomes available, and thus the future 2008 price will deviate from the current spot price.

Figure 3 shows the interest rates and implied yields (Y06/I06) calculated from spot and future 2006 prices using equation (3.4). This figure much more clearly illustrates deviations from the theoretical equilibrium relationship between spot and futures prices. It is striking that at the beginning of the sample period, the implied yield was obviously below the riskless interest rate. Notice from Table 2, that on average, the implied yield is 26 basis points below the riskless rate.
Who could have exploited these price relations? Before December 2005, one could have applied short arbitrage (reverse cash-and-carry) by selling the underlying spot and simultaneously entering into a long futures contract and investing at the riskless interest rate. This would have resulted in a riskless profit. To do so, one needs the underlying, meaning that only regulated emitters could have used this arbitrage possibility. Short-selling possibilities for banks or other investors were virtually non-existent at that time. This may be an explanation for why the arbitrage possibility existed. Once the first futures had matured in December 2005, the regulated emitters may have started to believe that the futures market was indeed performing well and that no delivery risk was involved.

Particularly in April/May 2006 and from then onwards, the implied yield from spot and future 2006 fluctuates strongly. On the one hand, there might have been different trading times for spot and futures contracts. On the other hand, due to the short time to maturity of the future 2006, very small relative movements in the prices of spot and future 2006 will then result in big changes in the implied yields. Figure 4 presents implied yields from the future 2006 and future 2007 prices without using spot data. The implied yield now fluctuates far less. Still it is clearly below the riskless rate until the beginning of December 2005 and remains very close to its supposed level at the riskless interest rate for most of the time thereafter. Even during the very volatile market phase in April/May 2006, when prices stalled by more than 50% in only a few business days, this relationship remained stable in levels, although it was a bit more volatile. April/May 2006 market participants learned about the contents of the national emissions reports for the first year of compliance by the EU member states. It became apparent that the market was by far not as short as expected. As a result, prices of EUAs dropped dramatically.

Figure 3 and Figure 4 both illustrate that the difference between implied yields and interest rates seems to move somewhat further away from zero again at the end of 2006. One possibly distorting effect vis-à-vis the cost-of-carry relationship between spot and futures when the end date of an EUA futures contract at the ECX is approached could be

[Insert Figure 3 and 4 about here]

Another reason might be that some regulated companies did not allow their traders to exploit these arbitrage opportunities merely for political reasons. Note that the bulk of EUAs was granted for free to regulated companies.
the relatively high tick size of EUR 0.05. During October and November 2006, EUA spot prices were in the magnitude of EUR 10. Thus, for futures with a remaining maturity of 1 month, the interest rate would have had to increase by about 600 basis points in order to induce an increase of the futures price by one tick. Combined with the different trading times for spot and futures contracts, it might thus be hard to identify the correct yield from futures contracts with rather short maturities. In March 2007, the tick size at the ECX was reduced to EUR 0.01.11

In the following, we will analyze the relevance of the deviations between observed and theoretical futures prices in more detail and formally test whether relations (3.1) and (3.4) hold for spot, future 2006, future 2007, and future 2008 prices.

4 Testing the No-Arbitrage Relationship

Our analysis of the cost-of-carry relationship and price discovery in the EU ETS draws heavily from the cointegration methodology. According to economic theory, discounted futures prices should equal spot prices in equilibrium and implied yields from spot and futures prices should equal riskless interest rates within the first trading period. Even if one concedes that there may be temporary disequilibria due to the immaturity of the market, in the long-term, discounted futures prices and spot prices should be cointegrated. The same is true for implied yields and interest rates. Due to our focus on bivariate systems where there is at most one single cointegration vector, we present results of the two-step estimation procedure of Engle/Granger (1987). However, results are robust with respect to alternative tests for cointegration such as the system-based techniques developed by Johansen12 with key benefits in a more general multivariate context. The cointegration methodology is widely used in the financial and commodity markets literature.13

11 An analysis of first period spot and future contracts beyond that date is not very instructive, however, because EUA prices quickly moved towards zero at that time and stayed there until the end of the period.


4.1 LONG-TERM DYNAMICS OF EQUILIBRIUM RELATIONSHIP

In a first step, we test whether the time series under scrutiny are cointegrated. To this end, we can

- either pre-specify the cointegration vector according to economic theory
- or explicitly estimate the cointegration relation.

Both alternatives are presented in the following. Univariate unit root tests (augmented Dickey Fuller (ADF), Phillips-Perron (PP)) on the levels and first differences indicate that all time series tested are integrated of order one. Results are available upon request.

**Pre-specified cointegration vector**

To verify cointegration with a cointegration vector specified from theoretical considerations we test whether the equilibrium errors $\nu_t$ and $\omega_t$ are $I(1)$. To this end, we chose the ADF, PP, and the Kwiatkowski, Phillips, Schmidt, and Shin (KPSS) tests. For the first two unit root tests, a significant test statistic means rejection of the assumption of a unit root in $\nu_t$ and $\omega_t$, and thus indicates stationarity. In contrast, the KPSS test assumes a stationary time series under the null hypothesis. A significant test statistic here indicates a unit root. For all of these tests, a truncation parameter is needed to select the autocorrelation lags. While for the ADF test, this parameter is chosen according to the Schwarz information criterion (SIC), the truncation parameters for the PP and KPSS tests are chosen according to the Newey-West automatic bandwidth method.\(^\text{14}\) Due to the structural break in December 2005, we conduct the analysis both for the whole sample period from June 2005 to November 2006 and for a shortened time period from December 2005 to November 2006. However, we only expect a good performance from the cost-of-carry approach during the shortened time period starting in December 2005.

Table 3 presents the results from the unit root tests both for the whole sample period and for the shortened time series. Truncation parameters are given in brackets. Although both $\nu_t$ and $\omega_t$ should be stationary with a zero mean, we include an intercept in the test regressions. An intercept might be necessary, for example, in the event that relevant interest rates for market participants differ from EURIBOR/EuroSwap mid-quotes by

\(^{14}\) For a description of the ADF, PP, and KPSS tests, see Dickey/Fuller (1979), Phillips (1987), and Kwiatkowski et al. (1992); for the automatic bandwidth method, see Newey/West (1994).
some basis points. It would also be necessary if a constant convenience yield were found to exist. As Table 3 illustrates, the intercepts are mostly insignificant. However, a regression without intercepts does not improve the in-sample fit; the Akaike (AIC) and SIC values are ambiguous. We thus do not explicitly report unit root tests without intercepts.

[Insert Table 3 about here]

Results for the whole sample period (the upper half of Table 3) are somewhat mixed. For combinations of spot prices with future 2006 or future 2007 prices (F06/TF06, F07/TF07, Y06/I06, and Y07/I07), the evidence is somewhat in favor of stationarity, as evidenced by the mostly significant ADF and PP tests. The KPSS test, however, rejects the assumption of stationarity. For the future 2008 the results argue against stationarity. The picture becomes clearer when looking at the lower half of Table 3, which shows the unit root tests for the sample period 12/05 - 11/06. The results now much more strongly support the view we expected from the beginning. For combinations of spot and future 2008 prices (F08/TF08, Y08/I08), the evidence is clearly against stationarity, whereas for combinations of spot and future 2006 and future 2007 prices (F06/TF06, F07/TF07, Y06/I06, and Y07/I07), our hypothesis of stationarity finds fairly strong support.

Estimation of the cointegration relation

As an alternative to pre-specifying the cointegration vector, we can estimate the cointegration relation by ordinary least squares and then test whether the residuals from this regression are I(1). For example for the combination F06/TF06 we run a regression

$$TF_{06} = \beta F06_t + u_t$$

to obtain the cointegration vector (1, - \beta). Given that we can reject the null hypothesis that the residuals are I(1), the regression parameter is estimated super-consistently (see Stock (1987)). By using standard ADF tests to check the stationary assumption of the residuals, critical values are calculated according to MacKinnon (1991). Table 4 presents the corresponding results for the various combinations for the periods 06/05 – 11/06 and 12/05 – 11/06.

Without surprise the ADF tests lead to very similar results as before when pre-specifying the cointegration vector. For the period 06/05-12/05 the results indicate that only for the combinations F06/TF06 and Y06/I06 the variables have a cointegration relation with corresponding cointegration parameter in Table 4, column 3. For those combinations the
null hypothesis of a unit root in the residuals can be rejected on the 5% significant level. For all other combinations the results are rather against the stationary assumption of the residuals and the corresponding cointegration parameter should not be interpreted.

Again, for the shortened period, the results are more in favour of our expectation at the beginning. For combinations of spot prices with future 2006 or future 2007 prices (F06/TF06, F07/TF07, and Y06/I06) the null hypothesis of a unit root in the residuals is clearly rejected on the 1% significant level. For all other combinations, the variables do not cointegrate.\(^{15}\) When looking at the cointegration parameter for the combinations F06/TF06, F07/TF07, and Y06/I06 further tests about their supposed level can be done within the VECM setup.

Overall, we interpret these results as evidence in favor of a stable long-term equilibrium relationship between spot and futures prices within the current trading period, especially after the arbitrage possibilities vanished in December 2005. As expected, the results clearly argue against the hypothesis of stationarity for the combinations including future 2008 prices. In 2008, a new trading period started and the corresponding spot allowances were not yet traded in the first trading period. If one needs to price the future 2008, it is first necessary to build an expectation about future spot prices in the second trading period and to add a suitable risk premium. This expectation may be influenced by the current spot price; however, additional information sources must be used in order to quantify the factors only affecting the second trading period, such as EUA allocations for the years 2008 - 2012.

### 4.2 SHORT-TERM DYNAMICS OF EQUILIBRIUM ERROR

Given the established cointegration relationship we can now analyze how prices respond to deviations from the long-run equilibrium relation. To this end, we refer to Engle/Granger (1987, p. 255f), who assert that a valid representation for two cointegrated variables \(TF_t\) and \(F_t\) is a vector error correction model. Let

\(^{15}\) To further support our assumptions of cointegrated time series we also conduct Trace tests within a VAR setup for the various combinations. See Johansen (1991) and Osterwald-Lenum (1992). Due to some outliers in the residuals the normality assumption is often not guaranteed so that these cointegration tests might be biased or misleading. Normality is presumed because for the Trace test Maximum Likelihood principles apply. Despite the fact that normality often failed, Trace tests lead basically to the same conclusions as the previous ADF tests with regard to the existence of a cointegration relation.
describe a bivariate system of equations, where \( S' = (TF_t, F_t) \) are theoretical and observed futures prices, \( \Delta S_t \) are first differences, and \( \alpha \) denotes a constant vector. The number of lags to be included in the model is denoted by \( k \). The lag length is chosen according to AIC or SIC. When both criteria suggest a different lag order, the significance of the lagged differences is checked in addition.

From our previous analysis, we know that \( TF_t \) and \( F_t \) are cointegrated with cointegrating vector \( \theta' = (1, -\beta) \). Thus (4.1) has cointegration rank \( r = 1 \), and with \( \delta' = (\delta^{TF}, \delta^{F}) \), we may factor \( \Pi \) as \( \Pi = \delta \theta' \). With \( \Phi_i = \begin{pmatrix} \beta_i^{TF} & \gamma_i^{TF} \\ \gamma_i^{F} & \beta_i^{F} \end{pmatrix} \), we may expand (4.1) to

\[
\begin{align*}
\Delta S_t &= \alpha + \Pi S_{t-1} + \sum_{i=1}^{k} \Phi_i \Delta S_{t-i} + \epsilon_i \\
&= \alpha + \Pi S_{t-1} + \sum_{i=1}^{k} \begin{pmatrix} \beta_i^{TF} & \gamma_i^{TF} \\ \gamma_i^{F} & \beta_i^{F} \end{pmatrix} \begin{pmatrix} \Delta TF_{t-i} \\
\Delta F_{t-i} \end{pmatrix} + \epsilon_i^{TF} \\
&= \alpha + \Pi S_{t-1} + \sum_{i=1}^{k} \begin{pmatrix} \beta_i^{TF} & \gamma_i^{TF} \\ \gamma_i^{F} & \beta_i^{F} \end{pmatrix} \begin{pmatrix} \Delta TF_{t-i} \\
\Delta F_{t-i} \end{pmatrix} + \epsilon_i^{TF}.
\end{align*}
\]

Because we already have specified the cointegrating vector, applying simple ordinary least squares estimations of each equation leads to consistent and efficient parameter estimates. Table 5 presents the estimation results of (4.2) for the combinations F06/TF06, F07/TF07, and Y06/I06 for the shortened sample period after December 2005. Moreover, results of a Wald test are given to check whether we can accept to restrict the cointegration vector to \( (1, -1) \) as the cost-of-carry hypothesis suggests.

First, Table 5 shows that for the combinations F06/TF06 and F07/TF07 we can indeed accept the cost-of-carry hypothesis with a high probability. Next, our interest is whether the disequilibrium is restored quickly or whether it persists over several days. Looking at equation (4.2), we notice that in order to have the equilibrium relation \( TF - \beta F = 0 \) restored in only one time step, the estimated coefficients must satisfy

\[
\begin{align*}
\beta^{TF} &= 1 \\
\gamma^{F} &= 1 \\
\gamma^{TF} &= 1.
\end{align*}
\]

We call the right-hand side of this equation the "speed of adjustment" and also report the corresponding values in the Table 5. A value of 1 means that the equilibrium relation is restored in one day, lower values mean that it takes longer, and a value of 0 means that the equilibrium is not restored at all. The estimated values of 0.78 and 0.71 show that the
spot and futures prices under scrutiny actually revert back rather quickly. Interestingly, the coefficients $\delta^F, \delta^F$ capturing the transitional dynamics to the equilibrium relationship reveal that a convergence is not reached while both series adjust towards the equilibrium. Rather, the negative sign of $\delta^F$ means that the future price reaction leads to further equilibrium divergence but the spot price reaction reduces the divergence with a price reaction being much higher than the future price reaction.\(^{16}\) Note that $\delta^F$ for the combination F06/TF06 is only borderline statistically different from zero, and for the combination F07/TF07 $\delta^F$ can not be statistically distinguished from zero. That means the adjustment back to equilibrium is fully captured by $\delta^{TF}$.

The picture looks somewhat different for the yield combination Y06/I06. First, the cointegrating coefficient is not as close to its supposed level compared to the prices and as a consequence a restriction (1, -1) is not acceptable. The adjustment parameter $\delta^Y$ of 2 shows that the implied yield from spot and future prices strongly responds to a deviation from the long-run equilibrium while, not surprisingly, the riskless interest rate does not adjust at all. Interestingly, the speed of adjustment measure of 0.92 shows that the equilibrium is restored very quickly.

### 4.3 PRICE DISCOVERY IN THE EU ETS

Finally, it is important to know how pricing-relevant information is processed in the market. Will new information show up in spot or futures markets first? In other words, which market is the center of price discovery\(^ {17}\) on exchanges? Volume data from Bloomberg shows that EUA futures trading is far more liquid than spot trading even for the most liquid futures contract under scrutiny. This is common in many commodity markets. A first guess would thus be in favor of the futures contract. Based on the estimated VECM, a variety of measures can be applied in order to assess the price leadership (see De Jong (2002) and Baillie et al. (2002)). Table 6 shows statistics that help to assess the contribution of spot and futures prices to price discovery.

\[^{16}\text{Heaney (1998) reports similar results for the London Metal Exchange Lead contract.}\]

\[^{17}\text{Spot and futures prices are usually tested in mature markets with very high data frequency. For example, Theissen (2005) uses data with a frequency of 15 seconds. For the as yet immature EU ETS, only daily data are available to us. However, in thinly traded markets, differences in price discovery between spot and futures contracts may also be observed on a daily data basis, as shown, for example, by Kavussanos/Nomikos (2003) for the freight futures market.}\]
Based on the coefficients $\delta^{TF}, \delta^{F}$ in the VECM we can calculate the common factor weight ($CFW$), a direct measure of the contribution to price discovery. See Gonzalo/Granger (1995) and Theissen (2002) for a formal justification of this measure. The contribution of the futures market to price discovery is obtained by

\[(4.3) \quad CFW^F = \frac{-\delta^{TF}}{\delta^F - \delta^{TF}}.\]

The adjustment coefficients $\delta^{TF}$ and $\delta^{F}$ from equation (4.2a/b) determine the permanent effect of a shock of the respective market on the system. In the definition given above, a $CFW$ of 1 means that this market contributes exclusively to price discovery. A $CFW$ of 0.5 means that both markets contribute equally to price discovery. Looking at Table 6 we see that for the futures market the $CFW^F$ is clearly above 1. This becomes clear when looking at the size of the speed of adjustment coefficients $\delta^{TF}$ and $\delta^{F}$. In both cases, the futures market reacts least to price movements in the other market indicating that futures prices are the main contributors to price discovery.

Another popular measure proposed by Hasbrouck (1995) assumes that price volatility reflects new information and considers each market’s contribution to the variance of the innovations to the common factor. When the error terms are correlated Hasbrouck’s information shares (IS) are not unique, but Baillie et al. (2002, p.320.) argue that the average of Hasbrouck’s upper and lower bounds provides a sensible estimate of price discovery. The two bounds of Hasbrouck’s IS measuring the contribution of the futures markets are obtained by

\[(4.4) \quad IS_{1,F} = \frac{\left(\delta^{TF}\right)^2 - \left(\sigma^{FTF}\right)^2}{\left(\delta^{TF}\sigma^F\right)^2 - 2\delta^F\delta^{TF}\sigma^{FTF} + \left(\delta^F\sigma^{TF}\right)^2}, IS_{2,F} = \frac{\left(\delta^{TF}\sigma^F - \delta^F\sigma^{FTF}\right)^2}{\left(\delta^{TF}\sigma^F\right)^2 - 2\delta^F\delta^{TF}\sigma^{FTF} + \left(\delta^F\sigma^{TF}\right)^2} \]

with $\left(\sigma^{TF}\right)^2, \sigma^{FTF}, \left(\sigma^F\right)^2$ representing the covariance matrix of $e^{FT}, e^F$ in (4.2). Table 6 reports the averages of these values for the combinations F06/TF06 and F07/TF07. Again, the values of 0.67 and 0.68 are above 0.5 and thus indicate that the futures market contributes most to price discovery.
Finally, we also perform Granger causality tests on the theoretical and observed future for the combinations F06/TF06 and F07/TF07.\(^{18}\) While the null hypothesis "Observed future does not Granger-cause the theoretical future" is clearly rejected for both combinations at the 1% significance level, the contrary null hypothesis "Theoretical future does not Granger-cause the observed future" is only rejected at the 5% significance level. Although we find bidirectional Granger causality the clearer effect comes from the futures market.

All three measures indicate that the futures market leads the price discovery process. This is consistent with results known from many financial and commodity markets.\(^{19}\) One reason may be the higher liquidity in the futures market. As opposed to spot contracts, transactions with EUA futures do not have to be accounted for in the emissions registers before maturity. Moreover, companies without their own EUA allocations can only achieve short positions in the futures and not in the spot market. Companies seeking reliable price signals in the EU ETS should therefore always start by looking at the futures market.

5 Conclusion

The purpose of this study was to examine the relationship between spot and futures markets for CO\(_2\) emission allowances in the EU ETS. Our hypothesis was that within a trading period, spot and futures prices can be described by the cost-of-carry approach. Although there existed obvious arbitrage possibilities in the market during the year 2005, empirical evidence suggests that after December 2005, spot and futures prices are linked by the cost-of-carry approach within the first trading period. Temporary deviations from this linkage may exist but generally vanish after only a few days. Moreover, it is shown that the CO\(_2\) futures market leads the price discovery process.

An important implication from our findings for energy producers and other market participants in the EU ETS is that EUA futures maturing within a trading period are suitable instruments for hedging CO\(_2\)-related risks. This is due to their strong and clear

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\(^{18}\) See Granger (1969).

\(^{19}\) See e.g. Chan (1992), Booth/So/Tse (1999), Kavussanos/Nomikos (2003), Theissen (2005), or Gonzalo/ Figuerola-Ferretti (2009).
linkage to EUA spot prices. For example, power producers selling power futures may at the same time hedge their need for EUAs in the EUA futures market.

In contrast, we argue that it is not very instructive to link spot and second period futures prices via some convenience yield approach. The simple reason is that due to the strict banking and borrowing restriction second period futures are written on a completely different underlying that is not actually being traded in the first period. Therefore, a convenience yield calculated in a backwards manner from first period spot and second period futures prices, such that the usual no-arbitrage pricing relationship holds does not reflect the real benefit, which accrues to the owner of the spot commodity as opposed to the owner of a futures contract. An understanding of the latter is however what will be needed as soon as we seek to price futures contracts within the second trading period that are maturing after 2012. Because policy makers have already signalized a smoother transition into a potential third trading period, we do not have to fear a third separate market. Rather banking possibilities then effectively allow for a linkage between second period spot EUAs and third period futures.
References


**Figure 1:** Observed future 2006 price versus theoretical future 2006 price. The solid line represents observed EUA prices for the future maturing December 18th, 2006 at the ECX. The dashed line represents the corresponding theoretical futures prices when the cost-of-carry argument using spot prices from Powernext and riskless interest rates is applied. Prices are in EUR.

**Figure 2:** Observed future 2008 price versus theoretical future 2008 price. The solid line represents observed EUA prices for the future maturing December 15th, 2008 at the ECX. The dashed line represents the corresponding theoretical futures prices when the cost-of-carry argument using spot prices from Powernext and riskless interest rates is applied. Prices are in EUR.
Figure 3: Implied yields from spot and future 2006 prices versus observed interest rates. The solid line represents the implied yield in per cent calculated with the cost-of-carry relationship using both futures and spot EUA prices (future maturing December 18th, 2006; data from Powernext and ECX). The dashed line represents the corresponding riskless spot interest rate observed in the market.

Figure 4: Implied yields from future 2006 and 2007 prices versus observed interest rates. The solid line represents the implied yield in per cent calculated with the cost-of-carry relationship using futures EUA prices for 2006 and 2007 (data from ECX). The dashed line represents the corresponding riskless forward interest rate observed in the market.
Table 1: Description of time series tested.

<table>
<thead>
<tr>
<th>Time series' name</th>
<th>Description</th>
<th>Mean</th>
<th>St. dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Observed futures prices</strong></td>
<td>EUR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F06</td>
<td>ECX future, maturing Dec. 18th, 2006.</td>
<td>20.47</td>
<td>5.37</td>
</tr>
<tr>
<td>F07</td>
<td>ECX future, maturing Dec. 17th, 2007.</td>
<td>20.95</td>
<td>5.46</td>
</tr>
<tr>
<td>F08</td>
<td>ECX future, maturing Dec. 15th, 2008.</td>
<td>21.23</td>
<td>3.71</td>
</tr>
<tr>
<td><strong>Theoretical futures prices</strong>¹</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TF06</td>
<td>Future 2006 calculated from Powernext spot price.</td>
<td>20.64</td>
<td>5.46</td>
</tr>
<tr>
<td>TF07</td>
<td>Future 2007 calculated from Powernext spot price.</td>
<td>21.30</td>
<td>5.59</td>
</tr>
<tr>
<td>TF08</td>
<td>Future 2008 calculated from Powernext spot price.</td>
<td>22.00</td>
<td>5.77</td>
</tr>
<tr>
<td><strong>Implied yields</strong>²</td>
<td>Per cent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y06</td>
<td>Yield calculated from spot and future 2006 price.</td>
<td>2.62</td>
<td>3.30</td>
</tr>
<tr>
<td>Y07</td>
<td>Yield calculated from spot and future 2007 price.</td>
<td>2.40</td>
<td>1.74</td>
</tr>
<tr>
<td>Y08</td>
<td>Yield calculated from spot and future 2008 price.</td>
<td>4.17</td>
<td>8.27</td>
</tr>
<tr>
<td><strong>Observed interest rates</strong>³</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I06</td>
<td>Spot rate corresponding to future 2006.</td>
<td>2.88</td>
<td>0.40</td>
</tr>
<tr>
<td>I07</td>
<td>Spot rate corresponding to future 2007.</td>
<td>3.17</td>
<td>0.50</td>
</tr>
<tr>
<td>I08</td>
<td>Spot rate corresponding to future 2008.</td>
<td>3.31</td>
<td>0.51</td>
</tr>
</tbody>
</table>

¹) Theoretical futures prices are calculated with the cost-of-carry relationship (3.1) using observed spot/futures prices for EUAs and observed interest rates.

²) Implied yields are calculated with the cost-of-carry relationship (3.4) using observed spot and futures prices for EUAs. Yields are expressed on an annualized basis.

³) Spot interest rates are determined from the observed riskless interest rate curve according to the maturity dates of the corresponding futures. Interest rates are expressed on an annualized basis.
Table 2: Descriptive statistics of equilibrium errors.

<table>
<thead>
<tr>
<th>Time series</th>
<th>06/05 - 11/06</th>
<th>12/05 - 11/06</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean of equilibrium error</td>
<td>Standard deviation</td>
</tr>
<tr>
<td>F06, TF06</td>
<td>-0.16</td>
<td>0.45</td>
</tr>
<tr>
<td>F07, TF07</td>
<td>-0.36</td>
<td>0.62</td>
</tr>
<tr>
<td>F08, TF08</td>
<td>-0.77</td>
<td>3.17</td>
</tr>
<tr>
<td>Y06, I06</td>
<td>-0.26</td>
<td>3.13</td>
</tr>
<tr>
<td>Y07, I07</td>
<td>-0.76</td>
<td>1.46</td>
</tr>
<tr>
<td>Y08, I08</td>
<td>0.85</td>
<td>7.96</td>
</tr>
</tbody>
</table>

Equilibrium errors are calculated with the relationship (3.3) for prices and with (3.5) for yields.

Table 3: Cointegration results: unit root tests of equilibrium errors.

<table>
<thead>
<tr>
<th>Period 06/05 - 11/06</th>
<th>ADF Intercept</th>
<th>ADF τμ (Lag SIC)</th>
<th>PP Zτμ (Lag NW)</th>
<th>KPSS (Lag NW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F06, TF06</td>
<td>-0.03</td>
<td>-3.45*** (4)</td>
<td>-14.47*** (13)</td>
<td>1.41*** (14)</td>
</tr>
<tr>
<td>F07, TF07</td>
<td>-0.03</td>
<td>-2.37 (4)</td>
<td>-9.88*** (13)</td>
<td>1.38*** (15)</td>
</tr>
<tr>
<td>F08, TF08</td>
<td>0.02</td>
<td>-0.87 (1)</td>
<td>-1.39 (1)</td>
<td>1.20*** (15)</td>
</tr>
<tr>
<td>Y06, I06</td>
<td>-0.12</td>
<td>-3.21*** (4)</td>
<td>-17.48*** (13)</td>
<td>-1.33*** (13)</td>
</tr>
<tr>
<td>Y07, I07</td>
<td>-0.07</td>
<td>-1.48 (10)</td>
<td>-14.29*** (14)</td>
<td>1.00*** (15)</td>
</tr>
<tr>
<td>Y08, I08</td>
<td>0.11</td>
<td>0.48 (0)</td>
<td>0.63 (3)</td>
<td>1.23*** (15)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Period 12/05 - 11/06</th>
<th>ADF Intercept</th>
<th>ADF τμ (Lag SIC)</th>
<th>PP Zτμ (Lag NW)</th>
<th>KPSS (Lag NW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F06, TF06</td>
<td>0.03</td>
<td>-13.47*** (0)</td>
<td>-13.47*** (2)</td>
<td>0.09 (2)</td>
</tr>
<tr>
<td>F07, TF07</td>
<td>-0.02</td>
<td>-12.49*** (0)</td>
<td>-12.52*** (4)</td>
<td>0.22 (6)</td>
</tr>
<tr>
<td>F08, TF08</td>
<td>0.05</td>
<td>-0.92 (1)</td>
<td>-1.10 (1)</td>
<td>1.27*** (12)</td>
</tr>
<tr>
<td>Y06, I06</td>
<td>0.51**</td>
<td>-13.63*** (0)</td>
<td>-14.04*** (7)</td>
<td>0.46* (7)</td>
</tr>
<tr>
<td>Y07, I07</td>
<td>-0.05</td>
<td>-1.12 (9)</td>
<td>-13.54*** (7)</td>
<td>0.50** (8)</td>
</tr>
<tr>
<td>Y08, I08</td>
<td>0.17</td>
<td>0.18 (0)</td>
<td>0.27 (5)</td>
<td>1.18*** (12)</td>
</tr>
</tbody>
</table>

*, **, and *** stand for rejection at the 10, 5, and 1 per cent levels. For the ADF and PP tests, the null hypothesis is the existence of a unit root; for the KPSS test, the null hypothesis is a stationary series. All unit root and stationarity tests assume an intercept and no linear trend. For the ADF test, the estimated intercept is also shown.
Table 4: Cointegration results: estimated cointegration relationship

<table>
<thead>
<tr>
<th>Period 06/05 - 11/06</th>
<th>ADF (Lag SIC)</th>
<th>$\mu$</th>
<th>estimated $\beta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>F06, TF06</td>
<td>-3.54** (4)</td>
<td>1.008238</td>
<td></td>
</tr>
<tr>
<td>F07, TF07</td>
<td>-2.41 (4)</td>
<td>1.017095</td>
<td></td>
</tr>
<tr>
<td>F08, TF08</td>
<td>-0.93 (1)</td>
<td>1.045268</td>
<td></td>
</tr>
<tr>
<td>Y06, I06</td>
<td>-3.59** (4)</td>
<td>0.459861</td>
<td></td>
</tr>
<tr>
<td>Y07, I07</td>
<td>-1.49 (4)</td>
<td>0.931412</td>
<td></td>
</tr>
<tr>
<td>Y08, I08</td>
<td>0.10 (0)</td>
<td>0.192447</td>
<td></td>
</tr>
</tbody>
</table>

Period 12/05 - 11/06

<table>
<thead>
<tr>
<th>Period 12/05 - 11/06</th>
<th>ADF (Lag SIC)</th>
<th>$\mu$</th>
<th>estimated $\beta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>F06, TF06</td>
<td>-13.46*** (0)</td>
<td>0.998558</td>
<td></td>
</tr>
<tr>
<td>F07, TF07</td>
<td>-12.47*** (0)</td>
<td>1.001146</td>
<td></td>
</tr>
<tr>
<td>F08, TF08</td>
<td>-1.03 (1)</td>
<td>1.015931</td>
<td></td>
</tr>
<tr>
<td>Y06, I06</td>
<td>-13.85*** (0)</td>
<td>0.459903</td>
<td></td>
</tr>
<tr>
<td>Y07, I07</td>
<td>-1.05 (9)</td>
<td>0.916547</td>
<td></td>
</tr>
<tr>
<td>Y08, I08</td>
<td>0.06 (0)</td>
<td>0.202157</td>
<td></td>
</tr>
</tbody>
</table>

*, **, and *** stand for rejection at the 10, 5, and 1 per cent levels. For the ADF tests, the null hypothesis is the existence of a unit root. All unit root tests assume an intercept and no linear trend. Critical values have been calculated according to MacKinnon (1991). Note, that the results remain qualitatively unchanged if the dependent and independent variables in equation (*) are replaced by each other. These results are not tabulated to save space and can be obtained from the authors on request.

Table 5: Estimation results for vector error correction models.

<table>
<thead>
<tr>
<th>12/05 - 11/06</th>
<th>Coefficient</th>
<th>restrict $\theta' = (1, -1)$</th>
<th>Speed of adjustment</th>
</tr>
</thead>
<tbody>
<tr>
<td>F06, TF06</td>
<td>$\delta^F$</td>
<td>$\delta^F$</td>
<td>$\chi^2(1)=0.5579$</td>
</tr>
<tr>
<td>F07, TF07</td>
<td>$\delta^F$</td>
<td>$\delta^F$</td>
<td>$\chi^2(1)=0.4017$</td>
</tr>
<tr>
<td>Y06, I06</td>
<td>$\delta^Y$</td>
<td>$\delta^Y$</td>
<td>$\chi^2(1)=528.88$</td>
</tr>
</tbody>
</table>

Note t-values in parenthesis, p-values in brackets. For the VECM the lag length has been chosen according to the AIC information criterion. For all combinations the suggested order was higher than recommended by the SIC information criterion. But in all cases the lagged differences were significant so we chose the higher suggested order to avoid problems with autocorrelated residuals. The speed of adjustment measure is calculated according to $-(\delta^T - \beta\delta^F)$ for prices and $-(\delta^T - \beta\delta^Y)$ for yields.
Table 6: Price discovery measures.

<table>
<thead>
<tr>
<th>Time series</th>
<th>$CFW^F$</th>
<th>$IS^F$</th>
<th>H0: TF does not Granger-cause F</th>
<th>H0: F does not Granger-cause TF</th>
</tr>
</thead>
<tbody>
<tr>
<td>F06, TF06</td>
<td>2.02</td>
<td>0.67</td>
<td>F-stat.=2.8134 (0.0163)</td>
<td>F-stat.=35.6030 (0.0000)</td>
</tr>
<tr>
<td>F07, TF07</td>
<td>2.00</td>
<td>0.68</td>
<td>F-stat.=2.4090 (0.0359)</td>
<td>F-stat.=33.4951 (0.0000)</td>
</tr>
</tbody>
</table>

$CFW^F$ reports the futures market’s common factor weight according to (4.3) while the information share $IS^F$ is the futures markets average of the upper and lower bounds given in (4.4). Granger causality tests have been calculated within the VECM setup. Note p-values in parenthesis.