TED TANDEMS: ARBITRAGE RESTRICTIONS AND THE US TREASURY BILL/EURODOLLAR FUTURES SPREAD

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ABSTRACT

This paper develops a profit function for the TED tandem from the cash-and-carry arbitrage conditions associated with Tbill and Eurodollar futures contracts. This profit function is then used to develop an arbitrage-based trading strategy. The performance of the trading strategy is evaluated using Chicago Mercantile Exchange closing prices over a 1983-1991 sample. The impact of changes in cash market yield curves on TED tandem profitability is assessed.

A tandem is a speculative intercommodity trade combining calendar spreads in different commodity futures contracts. A TED tandem is a trade where the calendar spreads involved are in Eurodollar (Euro) and US Treasury bill (Tbill) futures.[1] Using a profit function for the TED tandem derived from cash-and-carry arbitrage fundamentals, a speculative trading strategy can be formulated from the underlying arbitrage restrictions. This approach to specifying a trading strategy is consistent with the approach used in constructing differential repo arbitrage trades (e.g., Yano, 1989). Comparison of the relevant profit functions reveals that the TED tandem is a substantively different trade than the TED spread which combines naked positions in Tbills and Euros. While the profitability of a TED spread trade is based on forecasting significant cash market developments such as

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'flight to quality', the profitability of a TED tandem depends on the relationship of the net implied carry costs associated with the arbitrage trades determining Euro and Tbill futures contract prices for different delivery dates. Despite being well known spread trading strategies, both the TED spread and TED tandem trades have received little attention in the literature.[2]

A primary objective of this paper is to evaluate the importance of various factors which determine the profitability of the TED tandem. Following the method used in constructing differential repo arbitrage trading strategies, a profit function for the TED tandem is derived from the underlying arbitrage fundamentals. The performance of a trading strategy formulated using the profit function is evaluated using Chicago Mercantile Exchange (CME) closing prices over a 1983-1991 sample. More precisely, in the following, Section I outlines the differential repo arbitrage approach. A basic profit function for the TED tandem is also provided. Section II reviews the cash-and-carry arbitrage conditions for Tbill and Eurodollar futures contracts and develops a TED tandem profit function using those conditions. In Section III, this profit function is evaluated using cash market data to provide the *prediction* that a long tandem trade will be profitable, on average. The mechanics of the long tandem trading strategy are discussed and difficulties in implementing the differential repo arbitrage approach are identified. Section IV provides empirical evidence on the performance of the long tandem strategy. Regression results are also provided regarding the impact of cash market yield curve behavior on tandem profitability. Finally, Section V summarizes the main results contained in the paper.

I. DIFFERENTIAL REPO ARBITRAGE AND PROFIT FUNCTIONS

The terminology "differential repo arbitrage" was introduced by Yano (1989) to describe a class of speculative financial futures trading strategies.[3] Included in this class of trades are the turtles (Jones, 1981; Rentzler, 1986; Poitras, 1987) and stereos (Yano, 1989; Poitras, 1997). Turtle trades combine an appropriately tailed spread in, say, gold or Tbonds, with a naked money market futures position. Stereos combine two appropriately tailed spreads in, say, gold and copper or Tbonds and Tnotes. The profitability of these trades depends on changes in the difference between the implied repo rate from one financial future and some other interest rate, either another financial future implied repo rate, as in the stereo trades, or the interest rate on a money market futures, as in the turtle trades. When the difference between these two interest rates lies outside some predetermined boundary, called the "track" by Poitras (1987) and Yano (1989), a speculative trading opportunity is identified. The design of differential repo arbitrage trades requires the specification of appropriate position sizes for the contracts involved in the trade. The relevant position sizes for a differential repo arbitrage trade have been described by Yano as the "arbitrage configuration".

The golden turtle provides a useful illustration for the mechanics of differential repo arbitrage trading. The golden turtle involves a combination of tailed gold spreads and Eurodollar futures positions. By construction, the profitability of a tailed gold spread depends only on the change in the implied carry cost for gold, effectively the change in the 'gold interest rate'. The underlying long arbitrage condition for gold dictates that the gold interest rate cannot rise above the Eurodollar rate or there will be an arbitrage opportunity. Cash market traders will borrow at the Eurodollar rate, buy spot gold, short appropriately dated gold futures contracts and deliver the gold against the short position. Because the relationship between the gold futures and spot prices is determined by the implied 'gold interest rate', this cash-and-carry arbitrage will be profitable if the gold interest rate is above the Eurodollar rate. In practice, the spread between the gold interest rate and Eurodollar rate varies over time. At times the spread nears zero, at other times the spread can be over 300 basis points. Trading opportunities are identified by evaluating the current spread relative to upper and lower boundaries which determine "the track".

Is it possible to extend the concept of differential repo arbitrage to tandem trades involving only money market futures, such as the TED tandem? The similarities in the factors determining trade profitability suggest this would be a practical exercise. However, to make the extension, it is necessary to examine the underlying cash-and-carry arbitrage conditions in order to derive a profit function which can be used to specify a speculative trading strategy. Compared to differential repo arbitrage trades, the TED tandem has a useful simplifying feature. The stereo and turtle trades require an arbitrage configuration vector to be determined such that the basis point values for the component trades are equal. For the golden turtle example, this would involve determining the size of the tail for the gold spreads, and the number of gold spreads per Eurodollar futures position. The TED has the desirable property of having equivalent basis point value for changes in the two contracts involved, \$25 per basis point on both Euro and Tbill contracts. Hence, the "dollar equivalence hedge ratio" for the number of Euro contracts to Tbill contracts in the TED is one-to-one and the configuration vector is given.[4] The practical complications involved in applying the differential repo arbitrage approach to the TED tandem involve: how to determine the difference between the implied repo rates from the Euro and Tbill contracts such that particular observations can be recognized as being outside "the track"?

In order to provide the appropriate notation and terminology, consider the *profit function* on a 'long' TED trade (short the Euro and long the Tbill) which is established at time t and closed out at $t + 1$:

$$\pi = (\mathrm{EU}[t] - \mathrm{EU}[t+1]) + (\mathrm{TB}[t+1] - \mathrm{TB}[t]) = (\mathrm{EU}[t] - \mathrm{TB}[t]) - (\mathrm{EU}[t+1] - \mathrm{TB}[t+1])$$

where $\mathrm{TB}[\cdot]$ and $\mathrm{EU}[\cdot]$ are the invoice *prices* of the deliverable Treasury bills and Eurodollars underlying the CME IMM futures contracts.[5] In terms of the traded futures contracts, quotes at time t are $100 - r^b[t, \mathrm{N}]$ and $100 - r^e[t, \mathrm{N}]$ for the nearby (N) contracts, where $r^e[t, \mathrm{N}]$ is the implied interest rate on a Eurodollar futures contract for delivery at time N and $r^b[t, \mathrm{N}]$ is the implied interest rate on a Treasury bill futures contract for delivery at time N. Using these definitions, the long TED profit function in terms of changes in interest rates can be rewritten:

$$\begin{aligned}\pi_{\mathrm{TED}} &= \{(100 - r^e[t, \mathrm{N}]) - (100 - r^b[t, \mathrm{N}])\} - \{(100 - r^e[t+1, \mathrm{N}]) - (100 - r^b[t+1, \mathrm{N}])\} \\ &= \{r^e[t+1, \mathrm{N}] - r^b[t+1, \mathrm{N}]\} - \{r^e[t, \mathrm{N}] - r^b[t, \mathrm{N}]\} \qquad (1)\end{aligned}$$

Briefly, the *long TED* will be profitable when the EU-TB narrows or, put differently, $(r^e - r^b)$ widens. It follows that the *short TED* will be profitable when $(r^e - r^b)$ narrows. Section II demonstrates that the payoff on this trade depends primarily on changes in the *appropriately dated* cash TED.

Applying the concept of differential repo arbitrage depends on identifying the arbitrages which determine the cash, nearby and deferred TED spreads. On the delivery date for the futures contracts, the cash and futures TED spreads must be approximately equal.[6] The TED tandem aims to exploit discrepancies between the nearby and deferred TED spreads and, as a consequence, will have a profit function dependent on spread convergence. Defining the 'long' tandem as *short* the *deferred* Euro and *nearby* Tbill and *long* the *nearby* Euro and *deferred* Tbill, the associated *long* TED tandem profit function is, in terms of r^b and r^e:

$$\Pi_{\tan} = \{(r^e[t+1, \mathrm{T}] - r^b[t+1, \mathrm{T}]) - (r^e[t+1, \mathrm{N}] - r^b[t+1, \mathrm{N}])\} \\ - \{(r^e[t, \mathrm{T}] - r^b[t, \mathrm{T}]) - (r^e[t, \mathrm{N}] - r^b[t, \mathrm{N}])\} \quad (2)$$

Hence, the long tandem profits when the difference between $(r^e[\mathrm{T}] - r^b[\mathrm{T}])$ and $(r^e[\mathrm{N}] - r^b[\mathrm{N}])$ widens over time. Similarly, the *short* tandem is profitable when the difference between $(r^e[\mathrm{T}] - r^b[\mathrm{T}])$ and $(r^e[\mathrm{N}] - r^b[\mathrm{N}])$ narrows over time.[7]

II. CASH-AND-CARRY ARBITRAGE FUNDAMENTALS

The arbitrage restrictions which will be used to identify speculative trading opportunities for the TED tandem are associated with the different cash-and-carry arbitrages determining the Eurodollar and Tbill futures prices. More precisely, the mechanics of the cash-futures arbitrage for the two contracts implies that there is an inherent difference between the cash TED/nearby futures TED spreads and the nearby TED/deferred TED spreads. One significant reason for this difference is that Tbill futures with greater than nine months to maturity have a futures price which is undetermined by cash-and-carry arbitrage conditions, because the absence of a cash Tbill greater than 12 months to maturity undermines execution of the cash-and-carry arbitrage. In addition, the repurchase agreement market does not provide practical term financing rates needed to execute cash-and-carry arbitrages for the deferred Tbill contracts. Hence, there is the potential for different rates of futures-to-cash *convergence* for the nearby and deferred TED spreads producing relative mispricing of TED spreads for different delivery dates. A fundamental insight of the differential repo arbitrage approach is to recognize that spread trading profit opportunities can be modelled as deviations from cash-and-carry arbitrage conditions. Along these lines, a TED tandem trading strategy can also be designed which exploits the relevant cash-and-carry arbitrage conditions.

Consider the cash-futures arbitrage trades for nearby Tbill futures contracts (e.g., Kawaller and Koch, 1984; Dym, 1988; Hegde and Branch, 1985; Allen and Thurston, 1988). At time $t = 0$ (< N), the 'long' cash arbitrage involves purchasing a 91 + N day cash Tbill deliverable on a futures contract maturing at t = N, financed at the term repurchase agreement (repo) rate (R[t, N](N/360)). The cash and carry arbitrage is completed by shorting a dollar equivalent amount of futures contacts at (invoice) price TB[t, N].[8] The 'short' cash and carry arbitrage is similar. A Tbill deliverable at t = N is acquired by doing a term *reverse* repo at the reverse repo rate (RR[t, N]) with the appropriately dated Tbill as the underlying collateral. This Tbill is then simultaneously sold, generating the funds required for the reverse repo and creating a short position. Simultaneously, the short is covered by taking a dollar equivalent number of long Tbill futures contracts.

Assuming that the repo (borrowing) and reverse (lending) rates are equal, in other words that R = RR, accessing results available in Allen and Thurston (1988) or Poitras (1991), to a first approximation cash-and-carry arbitrage considerations require (see Appendix):

$$r^b[t, \mathrm{N}] = \mathrm{RTB}[t, 91 + \mathrm{N}] + \frac{N}{91}(\mathrm{RTB}[t, 91 + \mathrm{N}] - \mathrm{R}[t, \mathrm{N}]) \quad (3)$$

where RTB[t, 91 + N] is the interest rate on the cash Tbill at time $t = 0$ which is deliverable on a futures contract maturing at t = N. This result provides a direct relationship between: the interest rate implied in a specific Tbill futures contract; the cash rate for a Tbill which is deliverable on that contract; and, the financing rate applicable for the underlying arbitrage. However, as an arbitrage condition, equation (3) will only hold for some (N ≤ 9 months) Tbill futures contracts because there is no deliverable cash Tbill for contracts more than 9 months to delivery. In addition, the market for term repo in longer maturity ranges is thin and it is not possible to get term financing without significant rate deterioration.[9] Hence, the trading fundamentals which drive the nearby Tbill futures rates tend to differ from those for the deferred futures.

The arbitrage for Eurodollar futures differs fundamentally from that for Tbill futures. This follows because arbitrage financing for Tbills is done in the repo market while, for Euros, financing is done in the cash market and the futures contracts are actively arbitraged across the range of nearby and deferred delivery dates. As a consequence, the financing rate for Euros is determined by the implied forward rate in the cash market. To see this, consider a 'long' arbitrage for Euros. At time $t = 0$, funds for the arbitrage are borrowed by issuing a Eurodollar deposit at the N-day rate, RS[t, N] which matures on the delivery date for the Euro contract N days away. These funds are then invested for 91 + N days at the 91 + N day rate RL[t, 91 + N] and the resulting tail is covered by shorting the Euro contract at EU[t, N] with implied interest rate $r^e[t, \mathrm{N}]$. Unlike the Tbill case, the long Euro position is not deliverable on the futures contract, both because the Euro futures contract involves cash settlement and because the Euro deposit is non-negotiable. The position must be refinanced with the gain (or loss) on the futures position providing a mechanism to lock-in the borrowing rate.

Ignoring the bid/offer difference, the long arbitrage implies:[10]

$$(1 + \mathrm{RL}[t, 91 + \mathrm{N}]((91 + \mathrm{N})/360)) = (1 + \mathrm{RS}[t, \mathrm{N}](\mathrm{N}/360))(1 + r^e[t, \mathrm{N}](91/360)) \quad (4)$$

Taking logs and ignoring second order terms gives (see Appendix):

$$r^e[t, \mathrm{N}] = \mathrm{RL}[t, 91 + \mathrm{N}] + \mathrm{N}\frac{N}{91}(\mathrm{RL}[t, 91 + \mathrm{N}] - \mathrm{RS}[t, \mathrm{N}]) \quad (5)$$

Subject to caveats provided by Fung and Isberg (1993) and Sundaresan (1991), this indicates that the "arbitrage" equilibrium condition for Euros has the relevant implied forward rate in the cash market equivalent to the interest rate implied in the appropriately dated Euro futures price. Equations (3) and (5) can now be used to determine the equilibrium value for the TED:

$$r^e[t, \mathrm{N}] - r^b[t, \mathrm{N}] = (1 + \frac{N}{91})(\mathrm{TED}[t, 91 + \mathrm{N}]) - \frac{N}{91}(\mathrm{RS}[t, \mathrm{N}]) - \mathrm{R}[t, \mathrm{N}]) \tag{6}$$

where TED[t, 91 + N] = (RL[t, 91 + N] − RTB[t, 91 + N]) and, from equation (1), $\Pi_{\mathrm{TED}} = \Delta(r^e[\mathrm{N}] - r^b[\mathrm{N}])$. In words, the futures TED spread is determined by the cash TED with an adjustment for the difference between the (short) Euro rate and the term repo rate. When N = 0, equation (6) reduces to the arbitrage condition that cash and futures rates must be equal at maturity.

Given equation (6), a formula for the term structure of the TED spread relevant for the tandem can be calculated. Suppressing time dating for ease of notation:

$$(r^e[\mathrm{T}] - r^b[\mathrm{T}]) - (r^e[\mathrm{N}]\ r^b[\mathrm{N}]) =$$
$$(1 + \frac{N}{91})(\mathrm{TED}[91 + \mathrm{T}] - \mathrm{TED}[91 + \mathrm{N}]) - \frac{N}{91}(\mathrm{EUROYC}[\mathrm{T}, \mathrm{N}] - (\mathrm{R}[\mathrm{T}] - (\mathrm{R}[\mathrm{N}]))$$
$$+ \frac{T-N}{91}(\mathrm{TED}[91 + \mathrm{T}] - (\mathrm{RS}[\mathrm{T}] - \mathrm{R}[\mathrm{T}])) \tag{7}$$

where EUROYC[T,N] is the yield difference between the Euro rates for instruments maturing at T and N respectively and, from (2), $\pi_{\tan} = \Delta\{(r^e[\mathrm{T}] - r^b[\mathrm{T}]) - (r^e[\mathrm{N}] - r^b[\mathrm{N}])\}$. The upshot of equation (7) is that the difference between the nearby and deferred futures TED spreads depends theoretically on the relative slopes of the cash market Eurodollar and Tbill yield curves for different maturities. By introducing some heuristic empirical information about relative yield curve slopes, equation (7) can provide some insights into designing potentially profitable *tandem* trading rules.

III. TRADE SPECIFICATION AND DESIGN

From equation (7), arbitrage considerations dictate that the payoff on a TED tandem is primarily determined by changes in relative cash market yield curve slopes at different maturities. While it is apparent that the profitability of a tandem spread, $\pi_{\tan}$, will depend on changes in the components of equation (7), this result must be conditioned by observing that the three rhs parts of equation (7) all have different weights which will change over time. To see this, consider applying equation (7) to value a TED tandem for, say, a six month difference in the spreads (T − N = 182) with six months to the maturity date for the nearby contract (N = 182). After some fortuitous cancellation, equation (7) reduces to:

$$3\{\mathrm{TED}[15\text{ mo.}] - \mathrm{TED}[9\text{ mo.}]\} + 2\{(\mathrm{TED}[15\text{ mo.}]) - (\mathrm{RS}[6\text{mo.}] - \mathrm{R}[6\text{ mo.}])\} \tag{8}$$

Table 1. Cash Market Statistics for Daily Euro and US Tbill Yields

Sample: Sept. 3, 1985-Jan. 15, 1991 (Daily) NOB = 1322

	Mean	*SD*	*Min*	*Max*	*Skew*	*Kurt*
CTED3	0.897	0.378	0.24	2.69	1.216	2.624
CTED6	0.738	0.296	0.175	1.978	0.735	0.101
CTED12	0.565	0.248	0.098	1.874	1.052	1.203

Correlations

	TED3	TED6
CTED6	0.91357	
CTED12	0.83212	0.91413

	Mean	*SD*	*Min*	*Max*	*Skew*	*Kurt*
TB123	0.577	0.365	−0.300	1.75	0.448	−0.445
TB126	0.356	0.205	−0.330	1.098	0.520	−0.018
TB63	0.221	0.192	−0.440	1.020	0.801	1.195

Correlations

	TB123	TB126
TB126	0.92283	
TB63	0.91178	0.68322

	Mean	*SD*	*Min*	*Max*	*Skew*	*Kurt*
EU123	0.244	0.298	−0.500	1.125	0.111	−0.510
EU126	0.183	0.174	−0.250	0.625	0.158	−0.630
EU63	0.060	0.137	−0.375	0.563	0.199	0.119

Correlations

	EU123	EU126
EU126	0.96508	
EU63	0.94336	0.82350
TB123	0.79822	

	Mean	*SD*	*Min*	*Max*	*Skew*	*Kurt*
DTED123	−0.331	0.220	−1.437	0.605	−0.98	3.402
DTED126	−0.172	0.122	−0.786	0.613	0.006	2.915
DTED63	−0.159	0.161	−0.957	0.315	−1.342	3.783

Correlations

	DTED123	DTED126
DTED126	0.69242	
DTED63	0.83862	0.18766

Notes: 1 basis point = .01 and yields are expressed in bond equivalent form. The notation corresponds to: CTED3, CTED6, CTED12 are the cash TED spreads for the 3, 6, and 12 month maturities. EU123, EU126, EU63 and TB123, TB126, and TB63 are the yield differences between the 12, 6, and 3 month maturities with the shorter maturity being subtracted from the longer maturity. DTED123, DTED126, and DTED63 are the differences in the 12, 6, and 3 month cash TED spreads. SD is the standard deviation, Min is the minimum, Max is the maximum, Skew and Kurt are the centralized third and fourth moments.

Taking this result to be the value of the tandem when the trade is established, equation (7) can be evaluated for the limiting case when the spread is held until the nearby contract for the six month spread is at maturity:

$$\{TED[9\text{ mo.}] - TED[3\text{ mo.}]\} + 2\{(TED[9\text{ mo.}]) - (RS[6\text{mo.}] - R[6\text{ mo.}])\} \qquad (9)$$

If there is no change in any of the cash market interest differences, then the profitability of the tandem reduces to $\pi = 6(TED[9\text{ mo.}]) - \{5(TED[15\text{ mo.}]) + TED[3\text{ mo.}])\}$, a result which depends only on cash market TEDs.

Using π to provide a heuristic evaluation of the profitability of the TED tandem requires some empirical information. To this end, Table 1 provides estimates from daily *cash* market data for the 1985-91 sample period provided by the Bank of Canada. These results indicate that, on average: TED[12] = 56.5 bp, TED[6] = 73.8 bp, TED[3] = 89.7 bp. Extrapolating that TED[15] = 45 bp and TED[9] = 65 bp, it is possible to evaluate π for the simplified case of equation (7) applicable to a six month spread with a six month holding period. Recognizing that $\pi > 0$ in equation (7) indicates that a long tandem is profitable and $\pi < 0$ favors a short tandem, the empirical values indicate that the *long* tandem is profitable, implying that the difference between the spreads can be expected to *widen* over time. While this result is derived under *on average* conditions for a specific trade assuming unchanged yield curves, the potential profitability of the long tandem is also supported under other types of assumptions. However, to demonstrate this more generally requires equation (7) to be evaluated directly.

For example, recognizing from Table 1 that the slope of the Euro yield curve is relatively flat compared to the Tbill curve, the RTB[T] − R[T] term in equation (7) can be assumed to be negative because long term repo financing rates will arguably be above the return on the underlying Tbill, e.g., Allen and Thurston (1988). If the Tbill yield curve is flat at the longer maturities while the Euro yield curve is more steeply sloped and if there is no positive carry in the Tbill market (RTB = R), then equation (7) again indicates that the long tandem will be profitable. Because the profitability result for the long tandem only holds on average, there will also be situations where a short tandem is profitable. For example, when N is large and T-N is small, steepening of the US Tbill yield curve or flattening of the Euro curve could undermine the profitability of the long tandem. The upshot of all the possible scenarios is that tandem profitability depends on relative changes in Euro and Tbill yield curves. With this in mind, a key objective of Section IV also investigates how changes in cash TEDs relate to tandem profitability.

The theoretical relationship between cash market yield curves and tandem profitability is similar to an approach proposed by Kawaller and Koch (1992) in a hedging context. However, instead of deriving a hedging rule from cash-and-carry conditions as in the derivation of the TED tandem profit function developed in Section II, Kawaller and Koch use only a naive rationale to suggest that hedge performance can be improved by comparing the three month futures TED spread with the cash TED spread. More precisely, Kawaller and Koch demonstrate that when the futures TED differs from the cash TED by more than a predetermined basis point threshold, then this signals that a potential improvement in money market hedge performance can be gained by switching between Euro and Tbill futures.

Kawaller and Koch provide empirical evidence indicating a significant improvement in hedge performance if the rule is employed. While the trading signal in Kawaller and Koch does differ from the trading rule outlined above, it is likely that the signals from the trading rules will be similar suggesting that filtering the long tandem to account for the initial size of the tandem spread will enhance trade profitability.

Is it possible to manipulate equation (7) to specify a differential repo arbitrage condition? In order to derive a such a condition, it is necessary to manipulate equations (6) and (7) to express the left hand side as the difference between two repo rates, in this case (RS – R). Using equation (6), for the TED this produces:

$$\mathrm{RS}[t, \mathrm{N}] - \mathrm{R}[t, \mathrm{N}] = \mathrm{TED}[t, 91 + \mathrm{N}] + \frac{91}{N}(\mathrm{TED}[t, 91 + \mathrm{N}] - (r^e[t, \mathrm{N}] - r^b[t, \mathrm{N}])) \qquad (10)$$

Extending this result to the TED tandem requires differencing TED's for two different delivery dates N and T. Again suppressing time dating for ease of notation, manipulating equation (7) produces:

$$(\mathrm{RS}[\mathrm{T}] - \mathrm{R}[\mathrm{T}]) - (\mathrm{RS}[\mathrm{N}] - \mathrm{R}[\mathrm{N}]) =$$
$$\frac{91}{T}((\mathrm{TED}[91 + \mathrm{T}]) - (r^e[\mathrm{T}] - \mathrm{T}\, r^b[\mathrm{T}])) - \frac{91}{N}((\mathrm{TED}[91 + \mathrm{N}]) - (r^e[\mathrm{N}] - r^b[\mathrm{N}]))$$
$$+ (\mathrm{TED}[91 + \mathrm{T}] - \mathrm{TED}[91 + \mathrm{N}])) \qquad (11)$$

Following the methodology of the differential repo arbitrage trades, because equations (10) and (11) are determined from arbitrage relationships, the differences will be *theoretically* bounded. Empirical considerations could potentially be introduced to determine whether a specific difference is outside "the track" or predetermined boundary condition, at which point a trading signal is generated.

Unfortunately, while the differential repo arbitrage approach is appealing, practical implementation of rules based on equations (10) and (11) is *problematic*. One fundamental problem concerns the behavior of the conditions as N → 0. While the rhs term involving (91/N) is supposed to go to zero as N → 0 because the maturity basis is assumed to be zero, due to practical limitations of measuring the interest rates involved, there will tend to be small measurement errors due to factors such as differences in timing, problems of resolving the bid/ask spread and so on. These errors will be magnified dramatically, both in absolute terms and relative to the (91/T) term, as the contract approaches maturity. Another, more practical difficulty is that, unless a large amount of cash market data for all relevant Euro and Tbill maturities is available and used, only a limited number of 'exact' trading signals are provided.[11] Another practical difficulty of using equation (11), as an exact condition, is that it would significantly restrict the spread lengths and trading horizons which could be used in constructing trades. Due to maturity restrictions on the cash Tbill, no nine month spreads would be possible, with trading horizons of only three months and less for spread lengths of six months and trading horizons of 6 months and less for three month spread lengths.

IV. TRADE PROFITABILITY RESULTS

A. The Data Set and the Interpretation of Trading Rule Profits

A series of daily mid-market Eurodollar and US Tbill *cash* market interest rates for the three, six, and twelve month maturities from Sept. 3, 1985-Jan. 15, 1991 was obtained from the Bank of Canada. Summary information for these rates has already been provided in Table 1. The futures contract data is composed of the daily CME IMM settlement prices for Euros and Tbills from Jan. 1983 to Jan. 1991 for the March, June, September, and December delivery dates. This data was obtained from the Centre for the Study of Futures Markets at Columbia University. Because settlement 'price' quotes are virtually identical to closing prices, it is likely that some trades could not be put on at the quoted prices.[12] Various related comments could be made along this line. For example, offer rates are more appropriate for doing exact calculations, because this is consistent with all trades being initiated by the speculative trader; though, in practice, this would tend to be an upper bound as some trades could be executed within the bid/offer. In addition, as the prices used are from actual transactions, it is not apparent from an observed closing transactions price whether the stated price was a bid, offer or mid-market quote. This further complicates the interpretation of the trade simulation results. Other related concerns are the appropriate treatment of transactions costs and the mistiming of closing quotes in the Tbill and Eurodollar markets.

How to correctly interpret results from empirical simulations of trading rule profits? It is difficult for studies of trading rule profits to avoid the types of concerns identified. For example, detailed bid/offer data is not readily accessible for use and, even if available, would not avoid the problems associated with using closing (bid/offer) prices. Because it is difficult to precisely capture actual trading conditions, the empirical information provided about trade profitability is only indicative. The significance of this observation depends on the objective of the trading rule study. In the present case, no attempt is being made to verify a null hypothesis, such as market efficiency, where the significance of trading rule profitability is used as an empirical test of the null. The primary objective is to provide empirical information on the factors which determine the profitability of a particular trading strategy. However, because market efficiency does imply fair pricing for futures contracts, it is not expected that a naive trading strategy will produce statistically significant profits after allowance for appropriate transaction costs. Following the discussion in Sections II and III, it is expected that TED tandem profitability will depend on changes in cash market TED spreads making market efficiency an issue of only tangential interest.

There are a number of possible routes to implementing and testing the *long tandem* trading rule specified in Section III. The on average profitability of the long TED tandem implies a general tendency for the futures TED to be wider than the cash TED. Empirical evidence is provided to support this conjecture. In practice, the long tandem will tend to be profitable because as N declines, the nearby Tbill contracts in the tandem approach maturity and become increasingly more affected by cash-futures arbitrage considerations. The resulting difference in futures-to-cash convergence rates for nearby and deferred contracts drives (r^e[N] – r^b[N]) down relative to (r^e[T] – r^b[T]) creating a long tandem spread-trading profit opportunity. It is an empirical question how far the maturity dates for futures contracts selected should be apart for the nearby contract to be affected by cash-futures

Table 2. Profitability Results for the Long Tandem Trades

Sample: Jan. 1983-Jan. 1991

Spread Length (Trade Horizon)	*End Date*	*Aver. BP Gain*	*SD*	*t-value*	*MIN*	*MAX*	*W-L-T*
3 Month	Mid	6.87	10.21	3.69	−17	26	25-5-0
(9 Month)	End	8.57	16.57	2.83	−33	51	21-8-1
3 Month	Mid	5.13	10.32	2.72	−16	30	18-9-3
(6 Month)	End	6.83	16.84	2.22	−28	49	19-11-0
3 Month	Mid	3.33	10.36	1.76	−17	24	18-10-2
(3 Month)	End	5.07	18.02	1.54	−35	58	19-10-1
6 Month	Mid	7.71	15.74	2.40	−25	40	19-5-0
(9 Month)	End	10.54	21.45	2.41	−39	62	18-4-2
6 Month	Mid	8.10	14.09	3.15	−22	30	21-8-1
(6 Month)	End	10.30	20.91	2.70	−33	63	21-9-0
6 Month	Mid	5.47	13.32	2.25	−22	30	21-9-0
(3 Month)	End	7.67	21.95	1.91	−41	72	18-9-3
9 Month	Mid	3.71	13.26	1.05	−23	23	10-3-1
(9 Month)	End	3.43	21.95	0.58	−41	37	8-5-1
9 Month	Mid	6.08	16.56	1.84	−28	36	15-10-0
(6 Month)	End	6.48	19.01	1.71	−37	40	17-8-0
9 Month	Mid	7.43	15.24	2.67	−27	41	22-8-0
(3 Month)	End	10.33	23.84	2.37	−39	78	19-11-0

Notes: Spread Length is the time between the nearby and deferred contracts; Trading Horizon is the time from trade initiation until the trade is terminated; 'End Date' is the date on which the trade is terminated, either mid-month or end-of-month; 'Mid' is the mid-month termination date, 2 weeks prior to the start of the delivery month of the nearby contracts; End is the end of month termination date, 1 day prior to the start of the delivery month of the nearby contracts; 'Aver. BP Gain' is the average profit on the trade in basis points; 'SD' is the standard deviation of the profit, in basis points; 'MIN' and 'MAX' are the minimum and maximum profits on individual trades, in basis points; 'W-L-T' is the number of winning (W), losing (L) and no gain (T) trades. Transactions and variation margin costs have *not* been incorporated in the results. t value is for the null hypothesis that profit is zero.

arbitrage factors while the deferred contracts are not. Because the payoff on the tandem depends on relative changes in interest rates, profits on this trade are dependent on small basis point moves. Considerable care was taken to ensure that trading rule profits did *not* originate from data errors.

Simulated trade performance depends on selection of the rules for initiating and ending a trade. From the sizable number of such possible rules, a naive rule is selected. The rule is naive because a long tandem position is always used and because the date on which the trade is initiated and terminated is arbitrary.[13] While this type of initiation and termination procedure may be inappropriate for other types of trades, such as the differential repo arbitrage strategies, a naive rule is useful in the current context. Among other reasons, this follows because it is expected that the bulk of change in the tandem will occur as the nearby contract approaches maturity. Three trade initiation dates are selected: three, six, and nine months prior to the start of the delivery month a long tandem trade is initiated. Two trade termination dates were used for each of the spread lengths considered: two weeks prior and one day prior to the start of the delivery month.[14] The first deferred contract used in the trading rule profit calculations is the September, 1983 delivery and the last deferred contract used is the September, 1991 delivery. While in most cases this resulted in 30 trades for each tandem spread length (T-N) examined, due to lack of data it was not possible to construct 30 trades for the two longest (6 and 9 month) trading horizons, for the nine month tandem spread length and the longest trading horizon for the six month spread length. Using all spread lengths, trading horizons and termination dates leaves a total of 486 (not independent) trades to be considered.

B. *Empirical Results*

The results of the simulated long tandem trades are given in Table 2. As in Section I, profit is calculated by evaluating the change in the nearby/deferred TED spread difference, in basis points, between the initiation and termination date. For example, consider the 9 month spread length using the Dec. '87 deferred and Mar. '87 nearby contracts. The 9 month trading horizon would begin on Monday, June 2, 1986. On that date the deferred TED spread ($r^e - r^b$) was 119 basis points and the nearby TED was 107. For the end-of-month termination date, the deferred and nearby TED spreads would be evaluated on Friday, Feb. 27, 1987, when the deferred spread is observed to be 103 bp and the nearby TED is 93 bp. For this trade, the tandem spread narrowed from 12 bp (119-107) to 10 bp (103-93), so the long tandem lost 2 bp. For all calculations of trade profitability, transactions and variation margin costs have been ignored. To incorporate these costs, subtract the relevant costs from the stated profits. For example, if commissions are assumed to be $25 per spread roundtrip, this would involve subtracting two basis points per tandem from the stated profits. Similar results apply if bid/offer spreads are incorporated.

The evidence provided in Table 2 suggests that a naive long tandem trading strategy, ignoring transactions costs, is marginally profitable, on average. For example, at $25/bp a position of 20 6-month tandem spreads established 6 months prior to the delivery month and held until the day before the delivery month began would have *averaged* a gain of $5,150, before deductions for transactions costs, variation margin and taxes. While there is a general pricing bias in favor of long tandems, the W-L-T results indicate that there are situations where the trade will lose money. For the three and six month spreads, the longer trading horizons were more profitable, however this result was reversed for the nine month spreads where the three month trading horizon produced the largest average profits. Following Rechner and Poitras (1993) and Lukac and Brorsen (1990), t-tests for statistical significance of the reported profits are also provided in Table 2.[15] These results reveal a substantive change in the rankings based on average profits. In terms of significance, the 3 month spread with a nine month holding period exhibited the best performance. While the profits for most of the trades examined are found to be statistically significant at conventional α levels, inclusion of transactions costs substantially reduces the number of significant results. For example, taking transactions costs to be a minimal two basis points per tandem, the significance of the t test for the 3 month spread with a nine month holding period and month-end termination date falls from 3.69 to 2.62.[16]

Table 2 identifies a distinct advantage, in terms of average profit, to holding the trade until the beginning of the delivery month as opposed to closing out the trade 2 weeks prior. (This tendency increases up to the final trading date in the delivery month.) Due to the greater volatility of profit for trades with end of month termination, the higher average profit is not typically reflected in statistical significance. The differing average profit behavior for trades with mid and month-end termination dates is almost surely due to the

Table 3. Results of Long Tandem Trade Simulations Using the Filter: $(r^e[T] - r^b[T]) - (r^e[N] - r^b[N]) \leq 2$ basis points

Sample: Jan. 1983-Jan. 1991

Spread Length (Trade Horizon)	*End Date*	*Aver. BP Gain*	*SD*	*t-value*	*MIN*	*MAX*	*W-L-T*
3 Month	Mid	9.76	6.7	5.94	1	22	17-0-0
(9 Month)	End	11.94	14.2	3.45	–5	51	13-3-1
3 Month	Mid	11.92	9.5	4.51	–8	30	12-1-0
(6 Month)	End	11.15	17.1	2.34	–28	42	10-3-0
3 Month	Mid	10.5	****	**	1	21	8-0-0
(3 Month)	End	18.25	****	**	0	58	7-0-1
6 Month	Mid	18.5	****	**	4	40	8-0-0
(9 Month)	End	14.38	****	**	–9	45	7-0-1
6 Month	Mid	16.00	13.7	3.86	–10	30	10-0-1
(6 Month)	End	15.36	21.6	2.35	–30	57	9-2-0
6 Month	Mid	13.00	****	**	5	24	7-0-0
(3 Month)	End	21.29	****	**	–8	72	6-1-0
9 Month	Mid	11.33	****	**	5	20	3-0-0
(9 Month)	End	13.67	****	**	–9	33	2-1-0
9 Month	Mid	10.75	****	**	–8	25	3-1-0
(6 Month)	End	9.75	****	**	–28	28	3-1-0
9 Month	Mid	19.63	****	**	4	41	8-0-0
(3 Month)	End	29.88	****	**	2	78	8-0-0

Notes: See Notes to Table 2. *** indicates that value is not calculated because the total number of observations was less than 10. Transactions and variation margin costs have not been incorporated into the results.

affect of cash-futures arbitraging operations driven by delivery considerations. For example, the closer the Tbill contracts get to maturity, term repo becomes more readily available at lower rates. It is likely that the impact of cash-futures convergence on contract pricing increases as the contract which is "on the run" gets closer to delivery. Further support for the hypothesis that futures-to-cash convergence of nearby contracts is a primary source of trading rule profitability can be found by comparing *correlations* (not reported) between: profits for the mid and month-end trades with the same spread length which are typically less than .7; and, profits for trades with the same termination date but with different spread lengths which are higher, typically greater than .8.

The evidence provided in Table 2 confirms the presence of an often sizable number of losing trades. This provides scope for improving trade performance. Before considering the regression evidence on the impact of cash market factors on tandem spreads, improvements in profitability due to the use of filter rules can be considered. Such rules restrict the number of long tandem trades which will be initiated. Adapting a naive approach similar to Kawaller and Koch, the filter rule is based on the basis point difference between the nearby and deferred contracts on the trade initiation date. Such a filtering procedure is aimed at capturing the usually positive basis point difference for the long tandem when the trade is at the termination date. In this fashion, initiating only trades with positive basis point differences at the initiation date will tend to eliminate trades with a higher probability of loss. However, as with other filter rules, there will be an offsetting reduction in the number of trades which are initiated. Whether average total profit will improve is an empirical issue.

Table 4. Selected Results for the TED Tandem Regressions, 1986–90:
$((r^e[T] - r^b[T]) - (r^e[N] - r^b[N]))_t =$
$b_0 + b_1 \text{CTED}_t + b_2 (\text{CTED[T]} - \text{CTED[N]}]_t + (b_3 ((r^e[T] - r^b[T]) - (r^e[N] - r^b[N]))_{t-1}$

1986

	Mean	*SD*	*Minimum*	*Maximum*	*NOB*
FTED12	1.15614	0.10659	0.99000	1.42000	127
FTED3	1.06079	0.12154	0.77000	1.31000	127
DFT123	0.095354	0.050894	0.020000	0.31000	127
DFT63	0.044961	0.040274	−0.010000	0.23000	127
CTED12	0.44389	0.12819	0.15689	0.78189	127
CTED3	0.79668	0.11684	0.51300	1.13800	127

Dependent variable: DFT123 NOB: 117 5 Month Spread Horizon: π = 6 bp
Mean of dependent variable = .097009 SD of dependent var. = .051633
Adjusted R-squared = .761864 Durbin-Watson statistic = 2.00351

Variable	*Estimated Coefficient*	*Standard Error*	*t-statistic*
C	.057703	.024515	2.35381
CTED3	−.028201	.018942	−1.48884
DCT126	−.042015	.026905	−1.56159
DFT123(−1)	.883766	.075910	11.6423

Dependent variable: DFT63 NOB: 42 2 Month Spread Horizon: π = 8 bp
Mean of dependent variable = .069762 SD of dependent var. = .060344
Adjusted R-squared = .772218 Durbin-Watson statistic = 1.81251

Variable	*Estimated Coefficient*	*Standard Error*	*t-statistic*
C	.250630	.093138	2.69096
CT3	−.165050	.065815	−2.50776
DCT126	−.190069	.102266	−1.85858
DFT63(−1)	.591608	.131351	4.50402

1987

	Mean	*SD*	*Minimum*	*Maximum*	*NOB*
FTED12	1.00258	0.12739	0.83000	1.30000	194
FTED3	0.88552	0.12613	0.72000	1.18000	194
DFT123	0.10537	0.028061	0.030000	0.20000	294
DFT63	0.035691	0.015918	−0.020000	0.080000	376
CTED12	0.36903	0.098121	0.14588	0.61178	194
CTED3	0.65664	0.12704	0.29000	1.20500	194

Dependent variable: DFT123 NOB: 44 2 Month Spread Horizon: π = −4 bp
Mean of dependent variable = .099091 SD of dependent var. = .019979
Adjusted R-squared = .189728 Durbin-Watson statistic = 1.54633

Variable	*Estimated Coefficient*	*Standard Error*	*t-statistic*
C	.050650	.022108	2.29103
CT3	−.859322E−02	.020246	−.424440
DCT123	.772014E−02	.036559	.211170
DFT123(−1)	.542344	.117567	4.61305

Dependent variable: DFT63 NOB: 122 5 Month Spread Horizon: π = −7 bp
Mean of dependent variable = .039836 SD of dependent var. = .021007
Adjusted R-squared = .635868 Durbin-Watson statistic = 1.94103

(continued)

Table 4. (Continued)

Variable	Estimated Coefficient	Standard Error	t-statistic
C	.016235	.010148	1.59984
CT12	−.019465	.013214	−1.47303
DCT126	.035302	.019179	1.84068
DFT63(−1)	.751787	.059984	12.5332

1988

	Mean	SD	Minimum	Maximum	NOB
FTED12	1.40241	0.069855	1.20000	1.71000	187
FTED3	1.38043	0.089370	1.17000	1.63000	187
DFT123	0.044042	0.071388	−0.15000	0.20000	287
DFT63	0.020807	0.037696	−0.13000	0.16000	384
CTED12	0.85883	0.22402	0.35948	1.87403	187
CTED3	1.39874	0.46500	0.57000	2.69000	187

Dependent variable: DFT123 NOB: 176 8 Month Spread Horizon: π = 22 bp
Mean of dependent variable = .022727 SD of dependent var. = .071334
Adjusted R-squared = .856503 Durbin-Watson statistic = 2.37540

Variable	Estimated Coefficient	Standard Error	t-statistic
C	.025596	.015883	1.61152
CT12	−.016474	.011235	−1.46639
DCT123	.011650	.723041E−02	1.61120
DFT123(−1)	.910439	.036553	24.9074

Dependent variable: DFT63 NOB: 40 2 Month Spread Horizon: π = 18 bp
Mean of dependent variable = .017000 SD of dependent var. = .066495
Adjusted R-squared = .901040 Durbin-Watson statistic = 2.29696

Variable	Estimated Coefficient	Standard Error	t-statistic
C	.056928	.037314	1.52562
CT3	−.029960	.025233	−1.18732
DCT126	−.046822	.034344	−1.36332
DFT63(−1)	.903405	.102056	8.85208

1989

	Mean	SD	Minimum	Maximum	NOB
FTED12	1.42587	0.078611	1.25000	1.59000	189
FTED3	1.37000	0.088257	1.11000	1.58000	189
DFT123	0.043712	0.050181	−0.12000	0.20000	229
DFT63	0.014323	0.033208	−0.080000	0.16000	303
CTED12	0.65224	0.19020	0.24136	1.20500	189
CTED3	1.08256	0.19177	0.66800	1.59500	189

Dependent variable: DFT123 NOB: 42 2 Month Spread Horizon: π = −14 bp
Mean of dependent variable = .035238 SD of dependent var. = .082054
Adjusted R-squared = .884839 Durbin-Watson statistic = 2.39392

Variable	Estimated Coefficient	Standard Error	t-statistic
C	.130521	.046878	2.78429
CT12	−.115069	.042239	−2.72426
DCT123	.181503	.073443	2.47136
DFT123(−1)	.747944	.110299	6.78104

Dependent variable: DFT63 NOB: 179 8 Month Spread Horizon: π = −3 bp
Mean of dependent variable = .024749 SD of dependent var. = .036076
Adjusted R-squared = .809755 Durbin-Watson statistic = 2.07092

(continued)

Table 4. (Continued)

Variable	*Estimated Coefficient*	*Standard Error*	*t-statistic*
C	.010412	.555635E–02	1.87397
CT12	–.010037	.636587E–02	–1.57664
DCT126	.013221	.010970	1.20520
DFT63(–1)	.893921	.051110	17.4901

	1990				
	Mean	*SD*	*Minimum*	*Maximum*	*NOB*
FTED12	1.20395	0.061036	1.08000	1.35000	86
FTED3	0.98419	0.19168	0.51000	1.20000	86
DFT123	0.21977	0.16351	–0.0100000	0.58000	86
DFT63	0.034593	0.098847	–0.13000	0.40000	270
CTED12	0.39056	0.094383	0.19300	0.88300	86
CTED3	0.51736	0.13689	0.26800	0.81300	86

Dependent variable: DFT123 NOB: 80 4 Month Spread Horizon: $\pi = 47$ bp
Mean of dependent variable = .221250 SD of dependent var. = .165731
Adjusted R-squared = .958269 Durbin-Watson statistic = 2.12009

Variable	*Estimated Coefficient*	*Standard Error*	*t-statistic*
C	.082990	.039190	2.11761
CT12	–.128977	.067679	–1.90573
DCT123	.101584	.055113	1.84318
DFT123(–1)	.933480	.044018	21.2066

Dependent variable: DFT63 NOB: 42 2 Month Spread Horizon: $\pi = 31$ bp.
Mean of dependent variable = .230238 SD of dependent var. = .086009
Adjusted R-squared = .920237 Durbin-Watson statistic = 1.40165

Variable	*Estimated Coefficient*	*Standard Error*	*t-statistic*
C	.040072	.030281	1.32332
CT3	–.051953	.052866	–.982717
DCT126	.043713	.028661	1.52515
DFT63(–1)	.930893	.062756	14.8336

Notes: Tandem profits are calculated to end-of-month prior to delivery month. Calculated standard errors are heteroskedastic-consistent estimates. FTED = FT is the futures TED, CTED = CT is the cash TED, DFTED = DFT is the difference in the futures TEDs, DCT is the difference in the cash TEDs and C is the regression constant.

Trade profitability results using a two basis point filter are reported in Table 3. Within practical limits, other filtering levels generally produced monotonically similar results: lower filtering levels resulted in less trades and higher average profits. The filter rule involves calculating the difference between the nearby and deferred TED spreads on the initiation date. If the difference is less than or equal to two basis points then the trade is initiated. Otherwise, no trade is established. The evidence provided in Table 3 reflects a significant improvement in both the average and statistical significance of trade profit. As expected, this improvement comes at expense of a reduction in the number of trades, particularly for the nine month spread lengths where only three or four trades were initiated for the six and nine month trading horizons. The relative rankings of the trades in terms of average profit and statistical significance is similar to the unfiltered trade results. Of the trades which had a sufficient number of results, the three month spread with a nine month trading horizon has the highest level of significance. The nine month spread with a three month trading horizon has the highest average profit, followed by the six month spread with a nine month trading horizon. Both of these cases had only eight trades initiated.

What is the general relationship between the profitability of TED tandem trades and changes in the cash TED spreads? To investigate this question, a 1986-1990 subset of TED tandem spreads was examined in detail. A subset was used for two primary reasons: to control the number of results reported; and, to admit data limitations associated with the 12 month cash US Tbill. The subset was further restricted by considering only three spreads involving contracts within a given year. Taking the same three, six and nine month trading horizons, for each year there is one nine month, two six month, and three month spreads. Following the discussion in Sections II and III, for each trade length and horizon, the objective is to relate the dependent variable, the value of the TED tandem spread, $(r^e[T] - r^b[T])_t - (r^e[N] - r^b[N])_t$, with the independent variables, the associated values of a deferred cash TED, defined using the twelve month maturities, $(RL[12 \text{ mo.}] - RTB[12 \text{ mo.}])_t$, and a nearby cash TED, defined using either the three, $(RS[3 \text{ mo.}] - RTB[3 \text{ mo.}])_t$, or six month maturities, $(RS[6 \text{ mo.}] - RTB[6 \text{ mo.}])_t$. This produced a total of 180 possible estimated regression equations.

Initial estimates from regressing the tandem spread on the cash market spreads produced results with highly significant residual autocorrelation. A variety of unit root tests were then conducted, all of which verified the absence of a unit root in either the tandem spread or the cash spreads. Hence, cointegration techniques are not applicable. The resulting revised regression specifications included, in addition to the cash market spreads, the lagged value of the tandem spread as an independent variable. Representative results for this regression specification are reported in Table 4, together with statistics for the cash TEDs, futures TEDs and tandem values. For enhanced comparability of results, the same two types of spreads are used for each case: the DEC = T and MAR = N nine month spread and the JUNE = T and MAR = N three month spread, with different spread horizons being used for these two spreads in a given year. Regression results did not vary substantially whatever length of spread or trading horizon was used. Examination of the t tests for the relevant regression coefficients confirm that the level of the cash TED and the difference between cash TEDs of different maturities are only of limited significance to determining the daily level of the TED tandem. The most important determinant of the daily tandem level is the lagged tandem value.

Table 4 provides considerable evidence in favor of the hypothesis that tandem profitability is determined by futures-to-cash convergence for the nearby contracts. The t test results provide evidence that the futures TED is not actively arbitraged, up to the period when the nearby contract approaches maturity. Recognizing that the average value of the TED tandem composed of 3 month spreads, DFT63, is less than half the value of the TED tandem with 9 month spreads, DFT123, comparison of the standard deviations of the dependent variable for different spread horizons reveals substantially greater tandem volatility as the nearby contract approaches maturity. The small differences in the profits for different trading horizons also indicates that profitability is concentrated at the end of the trading horizon. Consistent with the analysis of equation (7) given in Section II, the futures TEDs, FTED12 and FTED3, are found to be wider than the cash TEDs, CTED12 and CTED3, indicating that a long tandem will tend to be a profitable trade. Combined with the evidence on convergence of the nearby TED spreads, this is further support for the hypothesis about the nearby contract futures-to-cash trading process determining tandem profitability.

V. CONCLUSIONS

A TED tandem is an intercommodity trade which combines calendar spread positions in U.S. Tbill and Eurodollar futures contracts. In this paper, a profit function for the TED tandem was developed from the underlying cash-and-carry arbitrages which specify the precise relationship between cash and futures TED spreads. Evaluating the profit function using actual cash market data indicated that a long tandem trade would, on average, be profitable. Based on an empirical examination of trade profitability, it was demonstrated that an appropriately specified long tandem trade will, on average, generate significantly positive profits if transactions costs are ignored. The strength of this result was dependent on both the spread length and the trading horizon. In addition, holding the trade until the day before the start of the delivery month was generally superior to closing out the trade 2 weeks prior to the start of the delivery month. Successful improvements to long tandem trade performance were achieved by using a naive filter rule. Consistent with the arbitrage restrictions specified in the TED tandem profit function, the relationship between long tandem profitability and the behavior of the cash market TED spreads was also examined.

The results of this study have both practical and theoretical implications. From a practitioner's perspective, speculative floor traders can gain empirical information about a potentially profitable trading strategy. The need to incorporate expectations about changes in cash market TED spreads to improve trade performance is identified. The theoretical implications point to an important question: does the presence of statistically significant profits for a speculative trading strategy imply that the market is "inefficient"? While numerous trading rule studies take profitable speculative trading strategies to be evidence of market inefficiency, it is important to recognize the conditions under which profitability was identified. Trade simulations are typically based on observed prices. In the present case, this involves transactions using deferred contracts that do not have a high degree of liquidity. Given the small basis point gains required for TED tandem profitability and the sensitivity of the statistical significance of profitability on the level of transactions costs, evidence of profitability may be confirmation of the trading profits of floor traders making markets in these contracts. This is consistent with the use of spreading techniques by floor traders to control risk associated with market making activity. Hence, the evidence of long tandem profitability presented in this study is only of indirect relevance to the issue of market efficiency.

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APPENDIX

I. Proof of (3):[17]

It is possible to derive this result directly from Allen and Thurston (1988), equation (1), by taking logs and observing that $m = \mathrm{N}$, $n = 91 + \mathrm{N}$ and $n - m = 91$. Equation (3) in the text follows with some minor algebraic manipulation.

A more detailed derivation involves identifying the relevant arbitrage trading relationships. To do this, let:

$$\mathrm{TB}[t, \mathrm{N}] = (1/(1 + r^b(91/360))) \qquad \mathrm{P}[t, 91 + \mathrm{N}] = (1/(1 + \mathrm{RTB}[t, 91 + \mathrm{N}]((91 + \mathrm{N})/360))).$$

where P[·] is the price of the *cash* 91 + N day Tbill, net of the interest earned between the purchase date and the delivery date of the futures contract. It follows from equation (2) that the total profit (excluding transactions costs) on the long arbitrage is:

$$\mathrm{TB}[t, \mathrm{N}] - \mathrm{P}[t, 91 + \mathrm{N}](1 + \mathrm{R}(t, \mathrm{N})(\mathrm{N}/360)) =$$
$$(1/(1 + r^b[t, \mathrm{N}](91/360))) - (1/(1 + \mathrm{RTB}[t, 91 + \mathrm{N}]((91 + \mathrm{N})/360)))(1 + \mathrm{R}[t, \mathrm{N}]) \leq 0$$

Dividing by P[t, 91 + N], taking logs and ignoring second order terms gives:

$$ln(\mathrm{TB}[t, \mathrm{N}]) - ln(\mathrm{P}[t, 91 + \mathrm{N}]) \leq \mathrm{R}[t, \mathrm{N}](\mathrm{N}/360)$$

Evaluating the logs on the left hand side and ignoring second order terms gives:

$$\mathrm{RTB}[t, 91 + \mathrm{N}]((91 + \mathrm{N})/360) - r^b(91/360) =$$
$$\mathrm{RTB}[t, 91 + \mathrm{N}](\mathrm{N}/360) + ((\mathrm{RTB}[t, 91 + \mathrm{N}] - r^b)(91/360)) \qquad \text{(A1)}$$

Similar calculations follow for the short arbitrage to get:

$$\mathrm{RR}[t, \mathrm{N}](\mathrm{N}/360) \leq ln(\mathrm{TB}[t, \mathrm{N}]) - ln(\mathrm{P}[t, 91 + \mathrm{N}]) \qquad \text{(A2)}$$

Further manipulation gives the other side of the inequality for equation (A1). Combining these results gives equation (3).

II. Derivation of Implied Forward Rate Formula

Standard presentations of the implied forward rate $r[t, t + 1, t + 2]$ for bonds give:

$$1 + r^*[t, t + 1, t + 2] = (1 + \mathrm{RL}[t, t + 2])^2/(1 + \mathrm{RS}[t, t + 1])$$

Taking logs and ignoring second order terms:

$$r^*[t, t + 1, t + 2] = 2\mathrm{R}[t, t + 2] - \mathrm{R}[t, t + 1] = \mathrm{R}[t, t + 2] + (\mathrm{R}[t, t + 2] - \mathrm{R}[t, t + 1])$$

This analysis extends immediately to the money market instruments under consideration here to get:

$$(1 + \mathrm{RL}((91 + \mathrm{N}/360)) = (1 + \mathrm{RS}(\mathrm{N}/360))(1 + r^e(91/360))$$

Taking logs, ignoring second order terms and solving for the implied forward rate gives:

$$r^e = \mathrm{RL} + ((\mathrm{N}/91)(\mathrm{RL} - \mathrm{RS}))$$

This is the same as (5).

NOTES

1. The acronym TED comes from combining (T)reasury bill with (E)uro(D)ollar.

2. Notable exceptions are Dym (1988), Siegel and Siegel (1990), Dubofsky (1992) and Landau and Wolkowitz (1987). In the trade literature, the TED has been examined in McGough (1985) and Windas (1996).

3. Differential repo arbitrage trades, being based on primarily on the use of boundaries derived from fundamental information, differ from trading strategies based on technical analysis, e.g., Levich and Thomas (1993), Lee and Mathur (1996).

4. As a tandem trade, the TED tandem also has the practical advantage of combining spreads in different commodities. Because each side of the trade is a spread, this allows for substantially lower transactions costs and margin requirements.

5. This presentation ignores the complication associated with pricing the Euro, where the futures price settles on yield, not price. Sundaresan (1991) demonstrates that this can complicate the relationship between implied forward rates and the futures rates. Another complication which is ignored is the asynchronous timing of the delivery dates for the Tbill, the first delivery date of the spot month for which a 13 week bill is available, and the Euro, the second London business day immediately preceding the third Wednesday of the spot month.

6. Some of the reasons why the futures TED at delivery will differ from the cash TED are: the Eurodollar delivery involves cash settlement based on an average of eight different banks; and, the different delivery dates for the Tbill and Euro contracts.

7. For example, assume at $t = 0$ that the nearby spread is 115 basis points and the deferred is 123. Further assume that at $t = 1$ the nearby spread falls to 95 basis points while the deferred spread stays relatively constant at 120 due, say, to futures-cash convergence factors affecting the nearby spread more than the deferred spread. In this case, a long tandem would have generated a profit of 17 basis points.

8. By convention, square brackets will be used to denote time dating, with the first element within the square bracket indicating the date of the transaction and the second element indicating the maturity or delivery date of the instrument. Hence, $R[t, N]$ is the (term) repo rate at time t maturing in N days.

9. Allen and Thurston (1988) provides evidence on rates for term repo out to 90 days and demonstrate the key role played by the repo rate in the cash and carry arbitrage. For long term repo, as the financing term increases the difference between the repo and reverse rates widens significantly to the point where the reverse rate is almost zero (Dym, 1988). In other words, while it may be possible to do term repos (and reverses) for distant months, the quoted financing rates are usually sufficient to deter arbitrage trading.

10. For Euros, dropping the bid/offer difference is much the same as assuming R and RR were equal for Tbills, i.e., the inequality conditions reduce to equality conditions. Hence, it is not necessary to consider the 'short' arbitrage condition.

11. A number of complications tend to make even the exact condition imprecise. For example, there is mismatching of the exact maturity dates for Euros and Tbills. The Euro delivery date is the second London bank business day immediately preceding the third Wednesday of the contract month. The Tbill delivery explicitly recognizes that the 12 month bill is only issued monthly, allowing for delivery to be made on three successive business days with the first delivery day being the first day of the spot month on which a

13 week Tbill is issued and a 1 year Tbill has 13 weeks remaining to maturity. There is typically only one time per month when the 12 month bill could be a deliverable bill.

12. Webb and Smith (1994) shows that the bulk of volatility in Eurodollar futures occurs at the open, not the close. It follows that the assuming trades can be established at closing prices may not be that severe for Euros.

13. This rule is naive because it ignores other information which may assist in identifying a trade initiation. Some trading rule studies, such as Poitras (1987) and Kawaller and Koch (1992), use dynamic rules which involve evaluating some condition or track each day. In the present case, this approach leads to variable trading horizons being used to calculate the profit for trades with a given spread length and, because more than one trade per horizon is usually indicated, this makes the results more sensitive to assumptions about transactions costs.

14. One reason for avoiding the delivery month in the trading simulations is that, even though the (four) delivery months for the Euro and Tbill contracts are identical, the contracts do have different expiration dates.

15. For a one-tailed t test that profit is greater than zero, the $\alpha = 5\%$ value is 1.645.

16. Assuming that the two spreads composing the tandem have a bid/offer spread of 1 basis point, the two basis point assumption is somewhat below the lowest transactions cost which can reasonably be assessed. The comparable t values for the three and four basis point transactions costs, applicable to conventional exchange floor traders, are 2.08 and 1.54.

17. The presentation here and in the text expresses the Tbill rate as a 'bond equivalent yield' (360 day year basis), not in discount rate form. This approach is used in order to express the Tbill rate, which is typically quoted as a discount rate, in a form which is directly comparable with the Euro-rate, which is quoted as an add-on rate in simple interest form (Stigum 1981).

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