How Two Profitable Trading Systems for Eurodollar Futures were Developed

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Abstract

Two trading systems for Eurodollar futures were developed using the *SAMM (Strategic Analysis of Market Method)* described in the book *The Strategic Analysis of Financial Markets (in 2 Volumes)* Moffitt (2017a,b). The *SAMM* formalizes the process of trading system discovery and development. It involves two steps that are seldom discussed: (1) a systematic method for discovering potential trading edges without data analysis, and (2) a method for appraising the likely life span of a system using "strategic life cycles." Using the SAMM, it is argued that futures expirations are likely "price distorters" because of semi-predictable FED actions, market segmentation of the yield curve, and probable inefficient forward markets. Using principal components analysis, independent components analysis, and smoothing methods, two trading systems having 20% maximum drawdowns over the period from 1990-2008 were developed. *System 1* traded 8 times per year for an annual return before fees of about 8.5% and *System 2* traded 4 times per year for an annual return before fees of about 15%. It is argued that disclosure of Systems 1 and 2 will likely attenuate their future performances due to changing the timing of Eurodollar rolls, but this will not occur immediately. We note that a system can be helped by publicity, as for example occurred after the Jegadeesh and Titman (1993) publication of the momentum anomaly.

Keywords: Trading System, Eurodollar Futures, ICA, PCA, Smoother, SAMM, Gambling, Betting, Trading, Algorithmic Trading, PPGS, Grationality, POPP

Contents

1 Introduction to the *Strategic Analysis of Markets Method (SAMM)*

The trading system we describe in this article was developed using the *The Strategic Analysis of Markets Method (SAMM)*, described in the book *The Strategic Analysis of Financial Markets (in 2 Volumes)* (Moffitt (2017a,b)) and summarized in the article Moffitt (2017c).

The *SAMM* assumes that there are inefficiencies in market prices which can be uncovered and exploited using a six step method. It is a constructive method, in the sense that its building blocks are human behavior and strategic thinking. It does not posit unrealistic axioms, as does efficient market theory. It requires the theory of gambling, because only good gamblers succeed in the market game. It requires a strategic life cycle model (the *POPP*) to explain how markets evolve over time. And it requires *behavioral finance*, the study of financial decision making, to explicitly involve humans. These elements are woven together logically to produce the *SAMM*.

The *SAMM* has six steps:

(1) Select potential *price distorters* (defined below) to generate trading ideas.

(2) Assemble datasets to investigate the *price impacts* associated with the price distorters.

(3) If Step (2) shows significant *price impacts*, formulate *strategic plans* therefrom.

(4) Create *Potentially Profitable Gambling Systems (PPGS's)* by converting *strategic plans* to *trading algorithms.*

(5) Perform backtesting of *trading algorithms* and iterate Steps (3)-(5) as needed.

(6) Upon the completion of Steps (1) through (5), locate the *strategic plan* in the *POPP* cycle and follow the evolution forward.

We begin by defining new terms that appear in these steps: *price distorter*, *price impact*, *strategic plan*, *trading algorithm*, *Potentially Profitable Gambling System (PPGS)* and the *Pursuit of Profits Paradigm (POPP).*

A *price distorter* is any exogenous news, constraints on trading, widely held beliefs, widely used strategies, or other regular market phenomena that have potential *price impacts.* It is difficult to appreciate this concept without some examples, but the core idea is this. All exogenous or endogenous happenings important to a market have the potential to "distort" prices, in the sense that prices would have been higher or lower in their absence. Many market participants unnecessarily limit the scope of this idea to concrete occurrences like dividend announcements, stock splits and so on. But it has much wider scope. For example, some strategies are price distorting, e.g. portfolio insurance and risk aversion. Structural factors such as the prohibition on shorting by mutual funds is distorting. Conventions established in the effort to organize markets (rules) such as futures and options expirations are potentially price distorting. The introduction of a new financial instrument, e.g. the S&P 500 index future in August, 1982 is often price distorting. And so on.

In trading jargon, a *strategy* is a set of rules or an *algorithm* that a trader, investor or computer uses to buy and sell. Strategies are often semi-formal schemas for action. For example, a strategy such as "In a bull market, buy popular, high-beta stocks; in a bear market, selectively short formerly popular stocks but hold them only for a short period," requires a determination of the type of market, bear or bull, and of criteria to determine "popularity" of stocks and holding periods for trades. While this form can be useful for *discretionary traders*, it is not specific enough for *algorithmic traders.* We call a strategy that lacks the specificity necessary for algorithmic trading, but which by a selection of specific *parameters* can be traded algorithmically, a *strategic plan.*

A *Potentially Profitable Gambling System (PPGS)* is a betting system for a financial time series $\{X_t\}$ that produces net positive expected returns before deducting expected slippage and costs of trading.

To convert a *strategic plan* into a *trading algorithm*, the best way is to perform analysis on market data in order to formulate PPGS's. In the strategic plan of the previous paragraph, for example, three sets of criteria are needed, (1) ones that identify the market type as bull, bear or neither, (2) ones that identify a stock as popular, and (3) ones that determine for a given market type and stock, when to buy and when to sell or short. If as the result of statistical analysis, we specify (1), (2) and (3) by

(1) Defining a bull market as one having positive 6 month returns, a bear market as one having negative two month returns on the Standard & Poors 500 Index and "neither bull nor bear" if these criteria point in opposite directions,

(2) Selecting NASDAQ stocks with 6-month beta and weekly turnover ratio in the upper decile of their respective distributions, and

(3) In bull markets, buying $\$10,000,000$ in *NASDAQ* popular stocks and selling when the bull ends, and in bear markets, shorting $\$7,000,000$ in *NASDAQ* formerly popular stocks for at least a week and remaining short as long as one month returns are negative and buying back when this criterion ends,

then the *strategic plan* has given rise to a *trading algorithm*. Of course, this plan is not entirely specific, i.e. the allocation to stocks is not detailed, beta can be specified in several ways using daily or weekly prices, the time and place of buying and selling is not specified, and so on. Using the strict requirement that a *trading algorithm* be produced, only a code snippet implementing the algorithm would convert the plan into an algorithm.

The *Pursuit of Profits Paradigm (POPP)* is based on the unremarkable premise that investors are mainly motivated by a desire for wealth, and that the impatient among them "chase after riches." Perhaps surprisingly (except to Warren Buffett), the predictability of the chase leads chasers to losses! Table 1 identifies four somewhat arbitrary phases in the evolution of the *POPP*.

Table 1: Phases in the Pursuit of Profits Paradigm (POPP)

Phase	**Name**	**Description**
(A)	Eureka!	Strategic Plan discovery by a few pioneers.
(B)	Early Copycat	Strategic Plan spreads sustainably.
(C)	Late Copycat	Strategic Plan spreads unsustainably w/positive reinforcement.
(D)	Crash	Strategic Plan crashes due to unanticipated trigger.

The POPP is not arbitrary or capricious. In fact, Moffitt (2017a) develops a logical argument and provides market examples. Many superior traders I've known employ some intuitive version of it. But its codification, to the best of my knowledge, is absent from the expository and academic literature. Since that codification requires lengthy development, and since the POPP plays a minor role in Steps (1)-(5) of the *SAMM*, the arguments that justify it are not presented here. Readers interested those arguments are referred to Moffitt (2017a).

Example 1.1 (Price Distorter: Earnings Announcements)**.** Earnings announcements have the potential to be exploitable *price distorters*. For Step (1) in the *SAMM*, we use our experience in markets to infer that positive surprises generally lead to stock appreciation and negative ones, to depreciation.[1] Of course, if the *price impact* has too short a horizon or is insignificant, it's of little use. But behavioral evidence (see Moffitt (2017a)) suggests that underreactions may occur when earnings are surprising, leading to post-event trends. Thus without any data analysis, we accept that earnings surprises are potentially tradable *price distorter*.

Step (2) of the SAMM requires us to assemble a dataset to investigate earnings announcements' *price impacts*. A promising analysis is shown in Figure 1. In Step (3) of

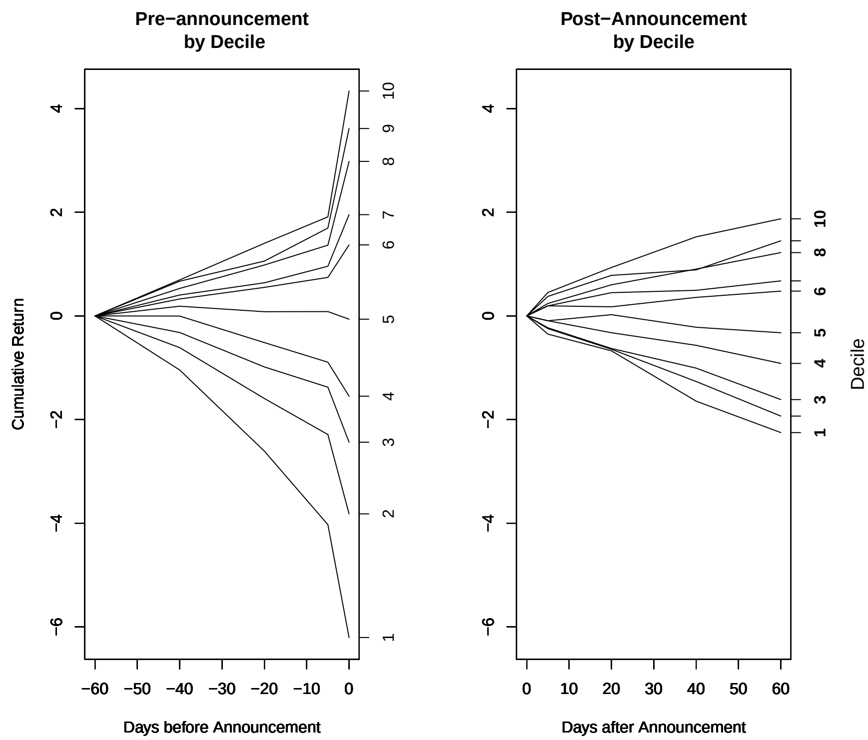

Figure 1: Standardized Unexpected Earnings Beat the Market? Earnings on this chart are defined as the ratio of a company's year-over-year earnings. For the sample of companies in the study, Standardized Unexpected Earnings (SUE's), defined as year-over-year differences in earnings divided by its standard deviation, were broken into deciles, the lower ones being "negative surprise earnings" and the upper ones being "positive surprise earnings." The left panel shows average price change (%) from 60 days prior to the announcement to the day of announcement, and the right panel show price changes from day of announcement to 60 days thereafter. Note that decile rankings are unchanged in the post earnings-announcement period. The steep changes in the left panel suggest insider trading, and the persistence of this effect thereafter is evidence of undervaluation at day -60. Source: Bernard et al. (1989).

the *SAMM*, we devise a strategic plan indicated by Figure 1: "Immediately after the earnings announcement, buy or short a stock in decile i in the amount $\$a_i$, hold for n

[1]This is not always true, especially at market turning points.

days then liquidate." In Step (4), we'd perform analysis to convert the strategic plan into a *trading algorithm* by finding good values for a_i and n. In Step (5) we perform appropriate backtesting using in-sample/out-of-sample methodology and iteratively improve the system as needed.

This example raises lots of issues that more thorough research should explore. First, the price impact analysis of Figure 1 should be refined. Are there groups of stocks or types of markets that are predisposed toward behavior different from the average? Second, the strategic plan is straightforward but too general. One should analyze price action prior to the announcement, for example. Since the Figure shows averages within deciles, it is unclear that a "follow-the-leader" strategy is viable; a similar plot could occur if individual stocks spiked up at random times. On the other hand, if price rises or drops were more regular, trend following might be a profitable strategy. Third, it would be advisable to vary the holding period using covariables such as type of market, performance of stocks in the same market sector, etc. Lastly we observe that Figure 1 doesn't mean that an acceptable *grational* trading system exists. And why is that? Since the graph shows average impacts, the trade will have edge in the long run, but might have unacceptable volatility along the way! That's the reason for Step (5), backtesting. ■

Example 1.2 (Price Distorter: Risk Aversion)**.** It may seem odd to think of risk aversion as a potential price distorter but the case in favor is impeccable. Consider the insurance business. Insurers allow risk averse owners of assets to purchase protection against loss; it is therefore sensible to expect some strategy to win against risk aversion. Figure 2 shows

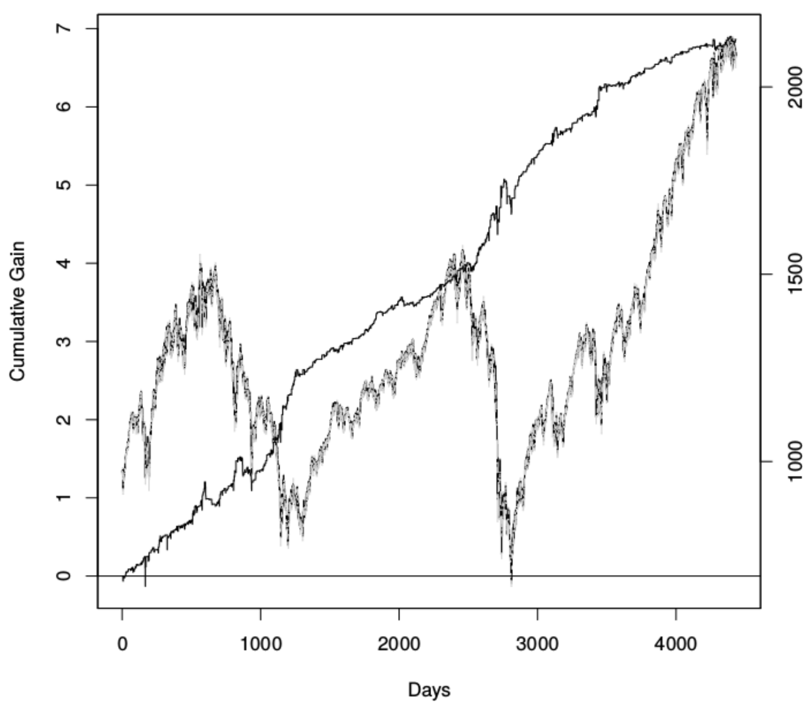

Figure 2: Plot of a trading system developed using the principles of *SAMM* with *risk aversion* as a *price distorter*. The dark line is the cumulative percentage gain of the system ($\sim$ 35% per year before fees — slippage is minimal. The gray line is the S&P 500 Index. Source: Moffitt (2017a)

the cumulative $P\&L$ for a trading system developed using SAMM principles. The dark line in Figure 2 shows the cumulative $P\&L$ and the gray line shows the S&P 500 index. The plot extends from 1998 until mid-2015. The axis to the left shows the cumulative gain beginning from a base of 1. Thus after about 17 years its return was 5-fold net of fees, but without any compounding, a return of about $5/17 \approx 0.29$, or 29% per year. In the last few years preceding mid-2015, its worst peak to trough drawdownwas about 12%, and the worst previous drawdown of 37% occurred after a 150% run-up in the middle of the plot. The algorithm for this mechanical system will not be discussed here, since it is not a robust algorithm in a sense discussed later in this article. Therefore if I disclosed how it works, it would doubtless cease to profit.

The hardest part of developing systems that exploit risk aversion is how to develop a strategy. It's not straightforward.
■

We begin by discussing the interest rate data used to develop an Eurodollar trading system.

2 The Dataset: Interest Rate Futures: 1981-2008

2.1 The Eurodollar Market

Since Eurodollar futures are used in our yield curve analysis, we present briefly some practical information about that market. An Eurodollar is a dollar time deposit held in a foreign bank. Because U. S. Dollars are the default currency in international transactions (e.g, crude oil is priced in dollars) and therefore are in demand in foreign markets, time deposits of Eurodollars generally have yields higher than U.S. Treasuries of comparable maturities. This is not the only reason for higher yields, but a discussion of others is beyond the scope of this article. The Eurodollar market is an interbank market and is not organized as an exchange, since its instruments are Eurodollar time deposits at banks. However, a standardizied set of maturities is offered by market-making banks — overnight, 1 week, 1 month, 2 months, 3 months and so on up to 10 years or more. Customized maturities can also be negotiated with a dealing bank. Each bank that participates in the Eurodollar market posts its own bids and offers, but bank markets are seldom significantly out of line with others for extended periods, since that invites arbitrage and basically, "gives away money."

Eurodollars time deposits are quoted using annualized simple interest assuming a 30/360 day count. This means that a three month ($3 * 30 = 90$) day \$1,000,000 Eurodollar time deposit made at 4% will pay

$$\$1,000,000 * \frac{4}{100} * \frac{90}{360} = \$10,000$$

to its holder at the end of 90 days.

2.2 Eurodollar Futures

2.2.1 Eurodollar Contract Structure

In 1981, the Chicago Mercantile Exchange (CME) introduced a series of futures contracts on 3 month Eurodollars. On the first trading day, December 9, 1981, only 3 contracts were offered, but by 1992, there were 40 contracts with expirations in March, June, September and December of the next 10 years. In general, the last trading day for quarterly contracts is the Friday preceding the third Wednesday of the contract month in March, June, September and December.[2] There are also *serial* Eurodollar contracts that trade monthly, but they are not as actively traded as quarterly ones; our analyses will only use quarterly contracts.

Because the CME wanted a futures contract that varied directly with rates, Eurodollar futures prices are quoted as $D = 100 - R$, where R is the Eurodollar rate. Thus a Eurodollar rate of 5% would be quoted as 95 in the CME Eurodollar futures market. The CME Eurodollar futures "underlying instrument" is the rate of a time deposit of $\$1,000,000$ for a 3 month Eurodollar time deposit — thus, a Eurodollar future with 500 days to maturity is really a bet on the 3-month Eurodollar time deposit rate that will obtain 500 days later.

Since there is no single interbank price for Eurodollars, these contracts at this writing settle against a EuroNext administered Eurodollar "'price fixing."[3] This does not cause problems, however, for two reasons. First, if the contract is out of line with interbank market prior to expiration or the fixing price at expiration, arbs will bring it back into line. In this case, the limits to arbitrage are technical and not believed to be significant,[4] and there is no shortage of money available for arbitrage. Second, the expiration process usually goes smoothly because of the way futures contracts settle. At the end of each trading day, any gains or losses in a contract are settled in cash by the counterparties, each having money added or withdrawn from their margin accounts by the CME's clearing house. Thus the impact of changes on the last day, which are usually small, affects traders' P&L's minimally.

Note that unlike some other futures, there is no settlement into a physical commodity, as in soybean, corn or crude oil contracts. Instead Eurodollar futures are "cash settled" into U.S. dollars.

2.2.2 Eurodollar Pricing Mechanics

As an example of the pricing mechanics, suppose that a contract settled yesterday at 94.60 and today at 94.63, where by definition of the CME futures contract, the implied annualized discount rate is

$$R = 100 - (\text{Eurodollar contract price})$$

[2] Actually, most contracts expire at 5:00 AM on Monday before the third Wednesday, but this detail is unimportant in our analyses.

[3] A major scandal erupted in July 2012 when a former trader disclosed that the fixing had been manipulated by banks (`https://en.wikipedia.org/wiki/Libor_scandal`) for their benefit. In January 2014, the EuroNext exchange assumed responsibility for administering the LIBOR.

[4] But riskless hedges are unavailable. (see Chance Chance (2002) and Tuckman and Serrat (2011)).

Since Eurodollar time deposits assume simple interest for all profit & loss calculations, the holder of 10 contracts would have

$$\left(\frac{(94.63 - 94.60)}{100} * \$1,000,000 * \frac{90}{360}\right) * 10 = \$750.00$$

transferred into his or her account after the close. The reason for the divisor of 100 is that an increase of 0.01 in the futures contract implies a decrease of one one-hundredth of one percent, or $-0.01\% = -0.0001$ in the fractional rate used in P&L calculations. A *tick* in a Eurodollar contract is defined as a change of 0.01 in the contract price, so a Eurodollar contract's value changes by

$$\$25 = 0.0001 * \$1,000,000 * \frac{90}{360}.$$

when the contract price moves by one tick. Knowing that the change in contract value for 1 tick is an invariant \$25, the previous calculation for 10 contracts can be foreshortened — there was a change of +3 ticks in the price from yesterday to today on 10 contracts at \$25 per tick, so

$$3 * \$25 * 10 = \$750$$

is the gain to a holder of 10 contracts.

2.2.3 Eurodollar Trading System Gains and Returns

This futures method of pricing has implications for the way trading P&L should be calculated. In particular, profits and losses should be calculated based on capital allocated to carrying the position, not the nominal value of the instrument underlying the future. The minimum amounts needed to carry a contract (margin deposits) are set by the exchange and are quite small compared to the nominal futures price. The minimum amount required open a contract is called the *initial margin*, which for Eurodollars in the low rate environment of October, 2015 is less than 30 ticks (\$750) for near term Eurodollar contracts, although margins increase in the back months. But even when rates were much higher, the initial margin was no more than 100 ticks. In general, the margining system for all futures contracts offers traders the option of high trading leverage; the futures margin for a physical commodity like crude oil or gold, for example, is between about 5% and 15% of its nominal value.

Initial margin must be deposited with the exchange's clearing house, a function that most traders manage through their brokers and clearing firms. In any case, each entity that trades in a futures market must maintain a margin account that is used to settle all gains and losses at the end of each trading day (See the CME web site for current margin requirements on Eurodollars). Often the initial margin is insufficient to carry a position for its duration, the reason being that the position can suffer losses sufficient to fall below a threshold level called *maintenance margin*. In that case, the exchange issues a *margin call*, which requests funds sufficient to restore the account to the initial margin level. For example, if maintenance margin is 75% of initial margin, and a big move in a position drops the margin account to 60% of initial margin, the exchange issues a margin call for 40%. If a trader doesn't produce those funds, the position is liquidated at market prices. In the worst cases, the losses can exceed the entire value of the margin account and the trader becomes liable for the losses.

One interesting wrinkle to margin accounts is that they can be funded by interest bearing instruments or securities. This has implications for return calculations which in the interests of simplicity we ignore in this article.

Because returns based on nominal contract prices don't always make sense for futures, we prefer using *gains per contract*, which we express in ticks. *Drawdowns* too are expressed in ticks, and become quite important for determining the level of funding for the margin account. In order to concentrate on the methods for identifying trading system edges, in this article we'll show that the trading systems we develop are viable without attempting to find optimal margining strategies. Given a system's gains and the margin used per trade, returns can be calculated as gains divided by average margins.

Average margins can be dangerous, though: "Did you hear about the trader who drowned crossing a river with an average depth of two inches?"

2.3 The Eurodollar Dataset

2.3.1 Some Practical Aspects of Eurodollar Futures Markets.

The major trading in Eurodollar futures occurs at the quarterly expirations. Typically, the prices of successive quarterly Eurodollar contracts trade at contract prices below those of their predecessors, and this behavior is due to the shape of the yield curve. The upper panel of Figure 3 shows a window of prices for two contracts, the SEP09 and DEC09, from April 14, 2009 to July 13, 2009. The vertical line is drawn at the JUN09 expiration date, June 12, 2009. The upper solid line shows daily closing prices for the SEP09 contract and the lower dotted line, those for the DEC09 contract. There are a total of 63 days, 41 prior to June 12 and 21 after. Note the unusual price action starting a week an a half before expiration, which has two large price moves in each contract, followed by a calmer period thereafter.

The lower panel of Figure 3 shows a time series of price differences for the two contracts. Note the marked difference in prices that coincides with the price move in the upper panel. As we'll see later, this price movement is not all that unusual!

There are always 40 quarterly Eurodollar futures contracts at the Chicago Mercantile Exchange; as one expires, another that expires 10 years later is added. This poses a challenge to trading system development for several reasons. First, only the 20 contracts that expire within 5 years are actively traded, so historical data for older, illiquid contracts is not particularly useful. Second, the most active contracts are those with no more than 2 years to expiration, because they are used as hedges. But in the low interest rate environment at the time of this writing (September 2015) trading activity has shifted toward the back month contracts.

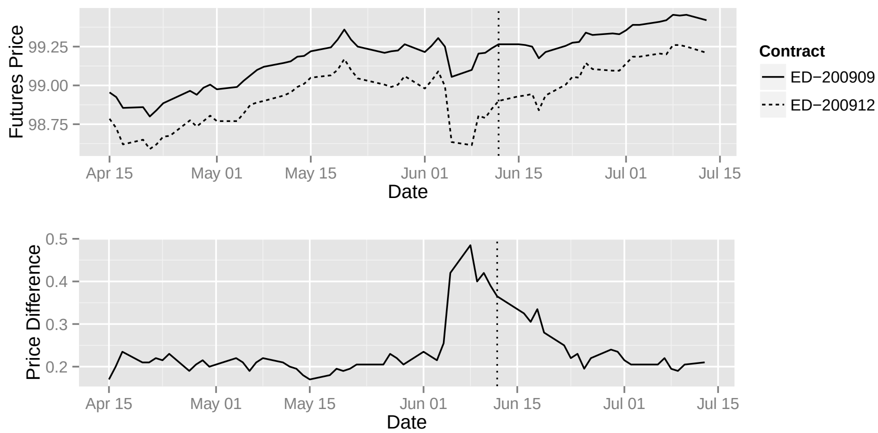

Figure 3: Time series plots of the September, 2009 (upper line) and December, 2009 (lower line) Eurodollar futures contracts from April 14, 2009 to July 13, 2009. The vertical line marks that June contract expiration day of June 12, 2009.

Eurodollar markets are characterized by having active hedgers and arbitrageurs on both sides, so one should not expect prices to deviate much from interbank markets. Third, as expiration of a contract approaches, and especially in the last month, its open interest begins to dwindle as traders who want to extend their positions begin rolling into the next contract months. The data challenge here arises from the abrupt discontinuity in prices that typically occurs between the currently expiring contract and the next-expiring one.

Figure 4 illustrates this problem. The upper panel's price series in Figure 4 consists of successive next-to-expire contract pasted together with no price modifications. Several large price jumps occurred in this 50 month period, but particularly noticeable are two in late 2001 and early 2002, due to the FED's reaction to 9/11. Look at the lower panel, which enlarges the interval from 2002-04-14 to 2002-08-16 demarcated in the upper by the two vertical dotted lines. That interval has a single expiration on 2002-06-14 shown with a dotted line; the prices for 6 days around that expiration are shown below:

```
            JUNE02   SEP02
2002-06-12  98.100  97.840
2002-06-13  98.110  97.880
2002-06-14  98.120  97.915
2002-06-17    ***   97.895
2002-06-18    ***   97.915
2002-06-19    ***   97.960
```

On Friday, 2002-06-14 the JUN02 contract expires, and on Monday, 2002-06-17 the SEP02 contract is the leading one. The Figure splices these two contracts together without making any price adjustments. Note that the jump of $97.895 - 98.12 = -23.5$ ticks in the leading contracts is entirely artificial, since the jump from Friday 2002-06-14 to Monday 2002-06-17 in the SEP02 contract is an unremarkable -2 tick.

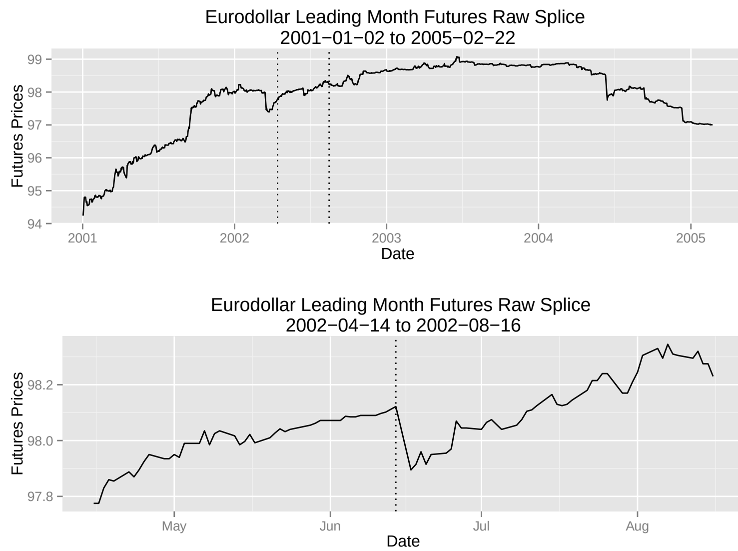

Figure 4: Eurodollar Leading Contract Plots. Leading month quarterly contracts expire on the second or third Friday of the contract month. The upper panel shows the history from 2001-01-01 to 2005-02-22. The lower panel shows the portion of the upper between the dotted lines, from 2002-04-14 to 2002-08-16, with the single quarterly expiration on 2002-06-14 shown in the lower with a dotted line. The closing price of the June contract on that Friday was 98.12, and of the September contract on the Thursday, 97.895, a sizable gap of -0.235.

For an analysis that needs a single "spliced together future" that never expires, there are a couple of popular methods for creating one. One uses a fixed day before expiration, say one or two weeks before, and another uses the day when open interest in the expiring contract falls below the next quarterly contract's open interest. Using these or some other method of identifying a *crossover day*, the exiting and entering future are spliced together by multiplying the next-month contract by a constant that makes the prices of the two contracts match on the crossover day. But variants of this method trade one problem for another — they eliminate discontinuities at the expense of distorting absolute, if not relative, prices. Of course, any method of splicing (or not) is feasible as long as the cash flows it implies can be realized in some trading strategy.

Nonetheless, the splicing method has important consequences for systems development. One should ask: if the crossover were chosen as 1 week before expiration, would a system trained on that data be the same as one using a crossover of 2 weeks? According to results in this article, probably not! In the next section, another method of creating a continuous contract is described, the *constant maturity* or *continuous splicing* method.

2.3.2 Constant Maturity Eurodollar Prices

Since we take Friday before the Wednesday of the contract month as our last trading day, and since successive contract months are three months apart, the time between last trading days will always be 91 or 98 days, which is either 13 or 14 weeks. Note that four consecutive 91 day contracts span 364 days, which is always 1 or 2 days short of a full year, so most contracts expire 91 days after the prior one. Therefore, by interpolating between two contracts on each trading day, a "constant maturity" contract that hypothetically "matures" in a constant 91 days can be created. For example, if the leading contract priced 93.75 matures in 30 days and the next one is priced at 94.00, the "constant maturity contract" "contract price" would be

$$\frac{30}{91}93.75 + \frac{61}{91}94.00 = 93.91758.$$

This calculation is sensible, because it continuously reduces the influence of the leading contract, allowing it no weight on its last day of trading. Of course, abrupt discontinuities can still occur in constant maturity contracts, due for example, to unexpected Fed actions, financial intermediary bankruptcies, and credit crises, but those types of events are rare, and in any case, should not be excluded by a constant maturity contract.

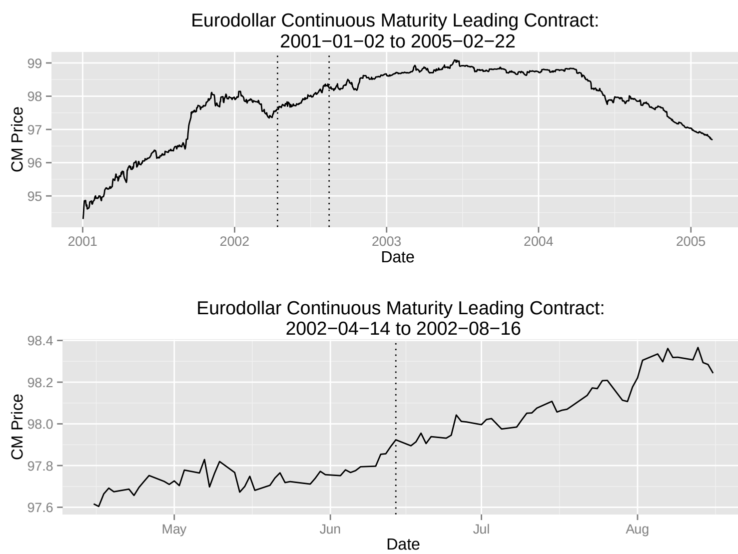

Figure 5: Eurodollar Leading Contract Constant Maturity Plots. These plots show the 91 day constant maturity contract for the same time periods appearing in Figure 4.

Figure 5 shows the first 91 day constant maturity contract for the same date ranges as Figure 4. Compare these two Figures and note the much smoother appearance of the constant maturity contract. In addition, this method avoids distorting the actual prices, as would the other methods mentioned in the last

Section. It might also be remarked that there is a obvious "bulge" from September 2001 to about March 2002; this was due to 9/11. After the attacks, the Fed lowered rates because they feared economic disruption. But when no crisis emerged, they returned policy to the former trajectory.

The dataset we use, *e2.3yr.cm.close.xts*, has 11 constant maturity contracts calculated using the first three years of contracts. The commands below show the first six rows:

```
> options(digits=4)
> head(e2.3yr.cm.close.xts)
           CLOSE.1 CLOSE.2 CLOSE.3 CLOSE.4 CLOSE.5 CLOSE.6
1992-06-23   95.80   95.28   95.14   94.72   94.26   93.74
1992-06-24   95.90   95.42   95.30   94.88   94.39   93.87
1992-06-25   95.95   95.50   95.38   94.96   94.48   93.96
1992-06-26   95.95   95.50   95.37   94.95   94.47   93.94
1992-06-29   95.99   95.57   95.42   95.01   94.51   94.00
1992-06-30   95.99   95.57   95.42   95.01   94.49   93.98
           CLOSE.7 CLOSE.8 CLOSE.9 CLOSE.10 CLOSE.11
1992-06-23   93.59   93.28   93.03    92.67    92.60
1992-06-24   93.71   93.40   93.15    92.78    92.68
1992-06-25   93.78   93.47   93.19    92.81    92.73
1992-06-26   93.77   93.46   93.18    92.81    92.72
1992-06-29   93.81   93.49   93.19    92.81    92.72
1992-06-30   93.79   93.48   93.18    92.80    92.72
```

In the analysis that follows, this dataset is used. There will be surprises ...

3 ICA Analysis of Constant Maturity Prices

3.1 Formal ICA Analysis

Figures 6 through 9 show a series of *independent components analysis*[5] analyses that suggest trading opportunities. Each uses the dataset *e2.3yr.cm.close.xts*, which has 11 "constant maturity" contracts formed from the first 3 years of Eurodollar futures contracts.

Recall that the k-dimensional *independent components analysis (ICA)* method we're using searches for the k least Gaussian components in the span of the k eigenvectors that have the largest variances, i.e. the first k *principal components analysis*[6] This has consequences for interpreting *ICA* analyses. For example, a 3-dimensional analysis will search in the space spanned by the first 3 eigenvectors, which is a superspace of the one used in a 2-dimensional analysis. In fact, each successive *ICA* analysis is done on a superspace of dimension one larger than the previous one. If the added orthogonal direction adds a new type of non-Gaussianity, then the components may be different in character from previous ones. We will see this below.

[5] A method of decomposing a multivariate dataset into components that are maximally independent. There are several different methods of calculating such components, depending on the measure of independence used.

[6] A method of decomposing a n-multivariate dataset into $m < n$ mutually orthogonal directions such that the sum of the variances associated with the directions is maximal over all other sets of m directions. PCA results from performing an eigenvalue decomposition of the covariance matrix and selecting eigenvectors associated with the m largest eigenvalues.

Now examine the 2-dimensional *independent components analysis (ICA)* analysis of Figure 6, which shows the two least Gaussian components in the subspace spanned by the first two *PCA* directions. Throughout this section and the entire article, we refer to time series of *ICA* or *PCA* components as *signals* and the profile of weights from which they are calculated as *signal profiles*. In this Section (but not always), signal profile, or just profiles for short, are stationary — meaning that they are unchanging weighted sums of current data.

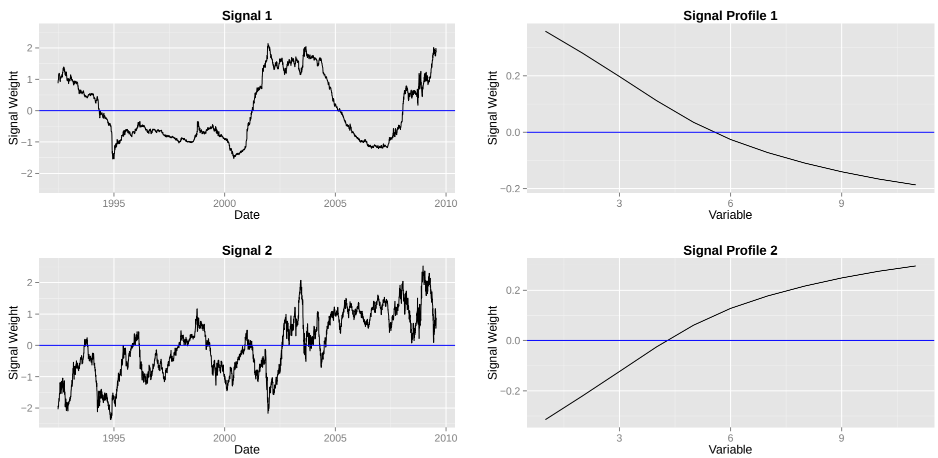

Figure 6: ICA 2-Dimensional Signal and Signal profile Plots.

There are three noteworthy features of the 2-dimensional components. First, the top one is much smoother than the bottom one. But that does not make it "smooth" in short time frames. That is because the entire time span of the series, the 18 years from 1992 to 2009, is quite long compared to daily, weekly or even monthly time horizons. On the other hand, the top plot shows promise because a long term trading system might be able to track it by ignoring the short-term wiggles. And since *ICA* components are nothing more than "constant maturity" portfolios, which in turn are portfolios of Eurodollar futures, the "signal" indicated by the top graph appears to be tradable.

Second, recall that *ICA* components are required to have zero means, a result of centering of the data that is part of the method. In the top plot, the long term movement is back and forth around 0, but in the bottom one, there appears to be a long term trend upward. One must be careful not to mistake this for price appreciation, since the signal graph of any component can be reflected around the horizontal axis by using an eigenvector of $-e$ instead of e. Since the algorithm for *ICA* utilizes a randomly-seeded search, it it typical that *signals* in one invocation will be inverted in another. Thus the uptrend in this *ICA* could just as easily have been a downtrend. The apparent reason for the long term drift is the gradual reduction of interest rates over the period of analysis, but there were also significant shorter term movements. These included a general lowering of rates by the FED from 9/11 to about mid 2003, then hiking through mid 2006 followed by a dramatic (and desperate) cutting thereafter due to the Global Financial Crisis of 2007-8. In fact, the entire component lies above the horizontal axis after about 2002, and the movements back and forth are probably some combination of changes in the levels of rates and yield curve shape changes.

Third, the top plot shows disruption in its right tail, e.g. starting around 2008 due to the *Global Financial Crisis of 2007-8*. Please note that the impact of this Crisis will have important implications for almost all the analyses we'll do.

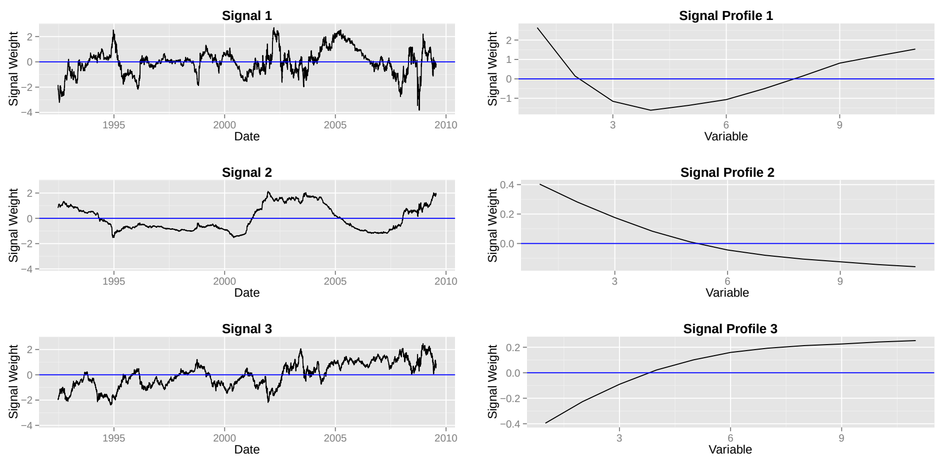

Figure 7: ICA 3-Dimensional Signal and Signal profile Plots.

Now compare the 2-dimensional analysis of Figure 6 with the 3-dimensional analysis of Figure 7. The first signal plot of Figure 6 is quite similar to the middle signal plot of Figure 7, but the signal profiles are different, with the weights of the second shrunken toward the horizontal axis compared to the first, and the back end reduced relative to the front end. It would seem that this component measures the steepness of the curve. Comparison of signal 2 of Figure 6 with signal 3 of Figure 7 suggests that the third eigenvalue "splits" off pieces of signals 1 & 2 of Figure 6 to produce signal 1 of Figure 7.

Figure 8 shows the 4-dimensional analysis, and its plots 2, 3 and 4 to those of 2, 3 and 1 of Figure 7, respectively, with signals 3 of the two plots inverted. Note first that each of the *signal profiles* has a cubic-like curvature. What is the cause of this, and is it problematic for this type of analysis? We examine this question later, but one important possibility involves the impact of the Global Financial Crisis.

Now look at the 5-dimensional analysis of Figure 9 — these *signals* and their *profiles* are really astounding. Can you see how a trading system might be developed from them?

The odd *signal* in Figure 9 is the 5^{th} one, which exhibits a highly non-random sawtooth appearance in its first half and at the end. The teepee shape repeats annually and is magnified in Figure 10. In this Figure, the upper panel exhibits a sawtooth pattern from 1992 to 2002, then seems to resume in 2008. What does

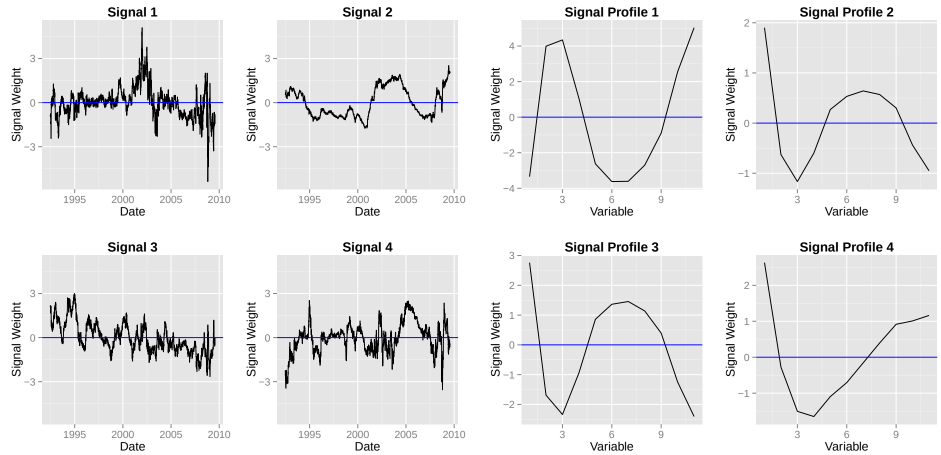

Figure 8: ICA 4-Dimensional Signal and Signal profile Plots.

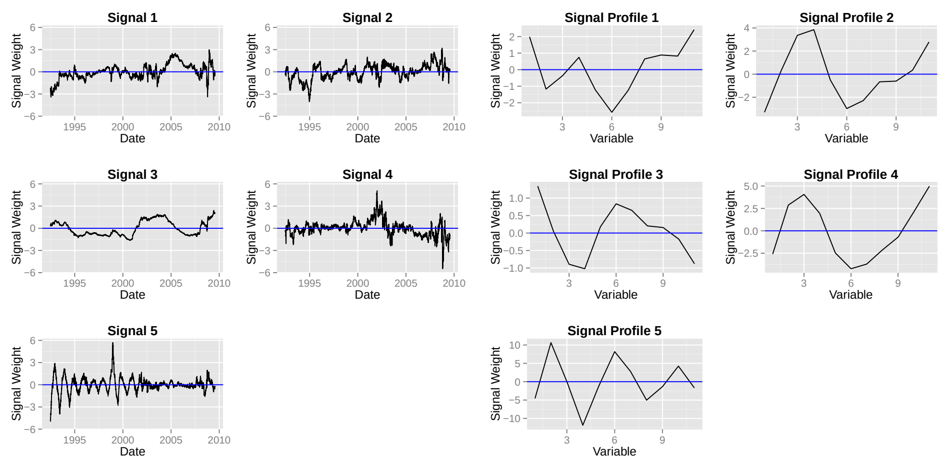

Figure 9: ICA 5-Dimensional Signal and Signal profile Plots.

the profile in the lower panel say about it? Recall that the ICA algorithm first centers each column, then forms signals by taking weighted sums of the variables. In the table below, those weights are shown for each signal. Thus the weight of the first constant maturity contract is -4.56. For the next constant maturity contract it's 10.64 and so on. The pattern is unmistakable: it reappears every 4 quarters with diminishing amplitude in each successive year until 1998. Then there is a spike in 1999 and the pattern disappears after 2002.

Data for the signal profile is shown below.

```
        SIG.1 SIG.2 SIG.3 SIG.4  SIG.5
CLOSE.1  1.99 -3.30  1.34 -2.60  -4.56
CLOSE.2 -1.17  0.26  0.05  2.88  10.64
CLOSE.3 -0.37  3.36 -0.89  4.07   0.03
CLOSE.4  0.75  3.85 -1.02  1.95 -11.85
```

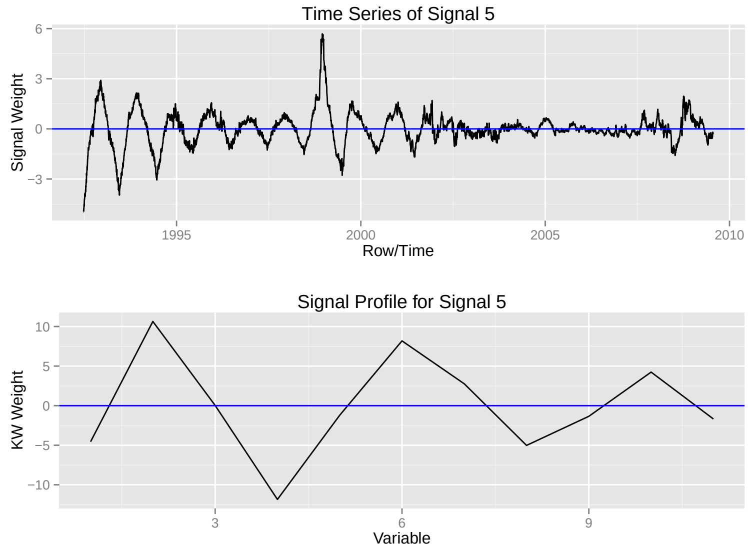

Figure 10: Magnified view of signal and profile for the 5^{th} ICA component in the 5-dimensional analysis.

CLOSE.5	-1.23	-0.50	0.18	-2.47	-1.21
CLOSE.6	-2.58	-2.98	0.84	-4.23	8.19
CLOSE.7	-1.24	-2.29	0.65	-3.71	2.76
CLOSE.8	0.65	-0.66	0.20	-2.14	-5.02
CLOSE.9	0.89	-0.60	0.16	-0.71	-1.35
CLOSE.10	0.82	0.35	-0.18	2.10	4.24
CLOSE.11	2.42	2.79	-0.88	4.99	-1.68

Clearly there is a trading opportunity for this signal in its early and late parts. Of course, the first question is: Are these signals tradable? That is, do portfolios exist that track these signals closely?

3.2 Can these Constant Maturity Signals be Traded?

Let's begin with a single constant maturity contract, say on the i^{th} day between contract k with price $P_{k,i}$ and contract $k+1$ with price $P_{k+1,i}$. The constant maturity price is

$$CM_{k,i} = \frac{91-i}{91}\,P_{k,i} \; + \; \frac{i}{91}\,P_{k+1,i}. \tag{1}$$

Suppose that we buy a CM contract on the i^{th} day and sell on the j^{th} day of the same 91-day period. Then the "gain" from the use of these prices is

$$CM_{k,j} - CM_{k,i},$$

for purposes of modeling. What does it take to replicate this gain? Consider the simpler case of $j = i + 1$ and assume that 91 total contracts are held on day i, $91 - i$ of k and i of $k+1$. On the close, sell one contract of k and buy one of $k+1$. Ignoring slippage and commissions, this is a costless transaction and has no impact on profit & loss. On day $i+1$, gains are earned on the CM portfolio. One can continue this strategy on each day between i and j, thus apparently achieving $CM_{k,j} - CM_{k,i}$.

Yet there is a serious flaw in this reasoning, which we'll show both by a logical analysis and a simple example. The logical analysis is this: a portfolio gain can be expressed as

$$\begin{aligned} G &= w_1 g_1 \, + \, w_2 g_2 \, \ldots \, w_n g_n \\ &= \sum w_i P_i^{'} - \sum w_i P_i \\ &= V(P') - V(P), \end{aligned}$$

where $P = (P_1, P_2, \ldots, P_n)$ are initial prices and $P' = (P_1^{'}, P_2^{'}, \ldots, P_n^{'})$ terminal prices, $g_i = P_i^{'} - P_i$ is the gain on the i^{th} asset, w_i is its weight for the entire period between P and P', and $V(P) = \sum w_i P_i$ is the value of a portfolio. But this formula does not apply if the weights change somewhere in the calculation.

Applying this principle to constant maturity contracts suggests that each day 1/91 of the nearest term contract should be sold, and 1/91 of the furthest term contract should be bought. However, this does not give the same payoff as $CM_{k,i+1} - CM_{k,i}$. To see this, observe that the strategy G of selling 1/91 nearer term contract and buying 1/91 further term contract exits previous positions in those futures, which we're assuming is costless by ignoring slippage and commissions. This strategy gives a 1 day payoff from the close of day i to the close of $i+1$ of

$$G = \frac{1}{91}(91 - (i+1))\,(P_{k,i+1} - P_{k,i}) \; + \; (i+1)(P_{k+1,i+i} - (P_{k+1,i}).$$

On the other hand

$$\begin{aligned} CM_{k,i+1} - CM_{k,i} &= (91 - (i+1))\,P_{k,i+1} \; + \; (i+1)P_{k+1,i+1} \\ &\quad - ((91 - i)\,P_{k,i} \; + \; i\,P_{k+1,i}) \\ &= G + P_{k,i} - P_{k+1,i} \end{aligned}$$

so that in general $G \neq CM_{k,i+1} - CM_{k,i}$ with equality only if $P_{k,i} = P_{k+1,i}$. However $P_{k,i} = P_{k+1,i}$ is generally positive (see, for example Figure 3) which gives constant maturity contracts an upward bias.

It is that upward bias which contributes to the sawtooth appearance of Figure 10. Here is an example:

```
           ED-199103  WT ED-199106  WT CM-PRICE
1990-11-08     92.31  81     92.32  10  92.3111
1990-11-09     92.37  80     92.40  11  92.3736

> # CM-PRICE(i+1) - CM-PRICE(i) =
> 92.3736 - 92.3111
[1] 0.0625

> # Sell 1/91 ED-199103, Buy 1/91 ED-199106 on the Close of 1990-11-08 =
> (80*(92.37 - 92.31) + 11*(92.40 - 92.32))/91
[1] 0.0624176
```

With closing futures prices as indicated for the two contracts on 1990-11-08 and 1990-11-09, the constant maturity price is given by the final column 'CM-PRICE'. Calculations for the one day difference in CM prices gives 0.0625, whereas the closing trade gain gives 0.0624176, a small but significant difference that favors the CM difference.

The foregoing discussion yields a fundamental principle of trading system development:

> **SYSTEM DEVELOPMENT PRINCIPLE #1**:
> For the trading of a single instrument, profits & losses should *ALWAYS* be calculated on a per trade basis, where a trade has an entering and an exiting transaction during which the position remains the same. For portfolios, per trade gains and losses should be aggregated.

3.3 Conclusions on the Constant Maturity Method

As we just saw, constant maturity prices are not tradable, in the sense that a difference between two such "prices" can be replicated with a trading strategy. The problem here is the unfortunate choice of the word "price" alongside "constant maturity," which creates the illusion that they act like any other prices. But of course, they don't.

Does this invalidate the analysis? Not necessarily, but it highlights a principle that should always be observed in trading systems development. A clear cut distinction should always be made between a trading system's signals, transactions and the operator that produces profits & losses. A signal is a sequence of functions f_t that maps information sets $\mathcal{I}_t$ (quantities that are known at time t) into transactions. There is a separate, time invariant profit & loss operator G that maps a sequence of transactions, prices and perhaps other variables, into gains and losses. Further layers of transformations that compute returns on a portfolio of systems can be quite complicated. But in this article, we ignore that complexity and calculate only $G \circ f_t(\mathcal{I}_t)$, the gains from the trading system; the constant maturity analysis of previous sections failed because we used an invalid G based on differences in constant maturity "prices."

But there is nothing wrong with constant maturity prices as signals — it's just that they should not also be used to evaluate the profitability of a system.This leads to another principle:

> **SYSTEM DEVELOPMENT PRINCIPLE #2**:
> In trading system development, distinguish carefully between signals, transactions and the P&L operator. PCA, ICA and other pattern recognition methods are tools appropriate for developing trading signals, and for assisting in the creation of transactions. But they have no place in the testing of a trading system's profitability; that activity should be done by a generic, standalone testing system.

Valid tests of trading ideas inspired by methods like PCA or ICA should generate trades. Each transaction either enters a trade or liquidates all or part of an existing one. A history of P&L's should be available in two forms: (a) a daily reporting of gains and losses, and (b) a trade summary that shows the entry and exit prices and times, the gain or loss, and if possible, summary statistics such as open, high, low , capture (the percentage gained divided by the maximum gain), the drawdown and so on.

I wish to state again why I measure gains, not returns. Using *grationality* terminology (see Moffitt (2017a,b) and the article Moffitt (2017c)), a trade that has a founding transaction at time t, a closing transaction at a later time t' and a constant position in between has a return equal to the sum of daily gains divided by the average funds reserved for margin. The return from time t to t' for a trading system consisting of several component systems will be the sum of all gains from its component trading systems divided by the initial value of the whole system. If you consider the design of software to perform these kinds of computations, perhaps you'll see why computing gains and saving other data that is useful in computation of returns leads to clean, modular software. Aside from simplicity of software, however, there is no compelling reason to prefer gains to returns.

In the next section, we consider a modification of the constant maturity analysis using a series of one-day gains that mimic constant maturity contracts.

4 Modifying the Constant Maturity Method

There is an obvious way to try to recover the last Section's constant maturity analysis, and it might produce something like Signal 5 in the previous analysis. Here is a description of the method.

1. Convert Eurodollar Contract prices to one-day gains and losses.
2. Create "constant maturity" gains and losses for each day using the sell front/buy back method.
3. Cumulate the gains.
4. Perform ICA and/or PCA analysis.

This method replicates the gains that would occur if on each day, a system sells one contract of the front and buys one of the back. We omit the details of the calculation, and show only the results. Figure 11 shows signals and signal profiles for an ICA 5-dimensional analysis. Note that the zigzag signal has disappeared! Apparently it was an artifact of the flawed method of creating constant maturity price series, and disappears when the tradable day-by-day profit & loss strategy is used.

Some of the signals may be tradable but we don't pursue that here.

Next, a PCA analysis is conducted. Figure 12 shows the PCA variances. Obviously, there is one, and only one, dominant component; it has more than 99% of the variance.

Figure 13 shows signal and signal profile plots for the PCA analysis. As usual, the signals are centered and the dominant Signal #1 appears to gain about $60*100$ ticks over a 20 year period, for an average of about 300 ticks per year. But this

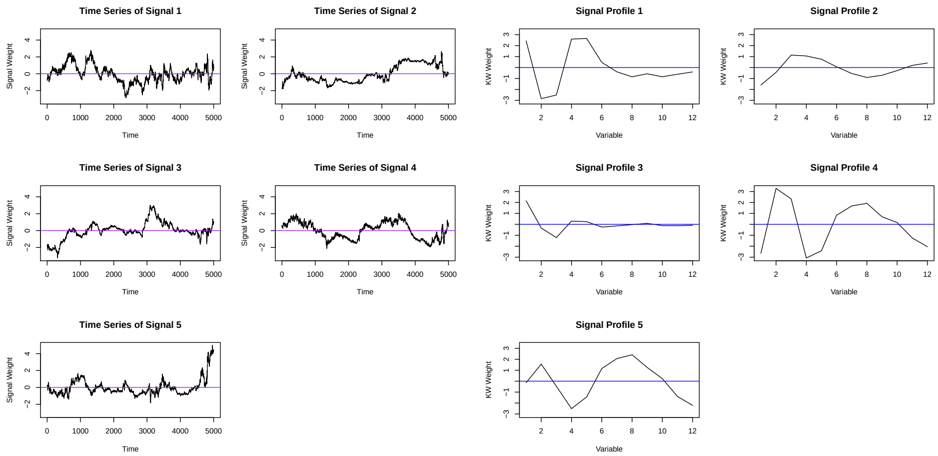

Figure 11: ICA for 5-Dimensional Signal and Signal profile plots of one-day cumulated "constant maturity" differences.

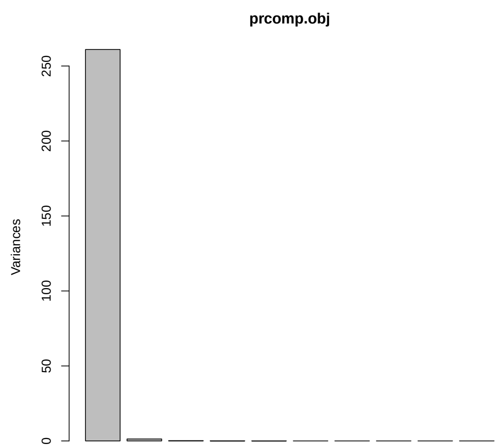

Figure 12: Variance Plot for PCA Components.

calculation is wrong! Recall that in a PCA analysis, the eigenvectors have unit Eulidean length. However, in order to qualify as a gains portfolio, the weights should sum to one or to some constant if leverage is used. Letting $e_1 = (e_{11}, e_{12}, \ldots, e_{1n})'$ be the first eigenvector, the proper weights for Signal #1 should be

$$\frac{e_1}{\sum_{i=1}^{i=n} |e_{1i}|},$$

where the absolute values are needed in case there are negative weights. For eigenvector #1, the sum of weights is 3.39; therefore, the gain per year should be normalized to $300/3.39 \approx 88.5$ ticks per year.

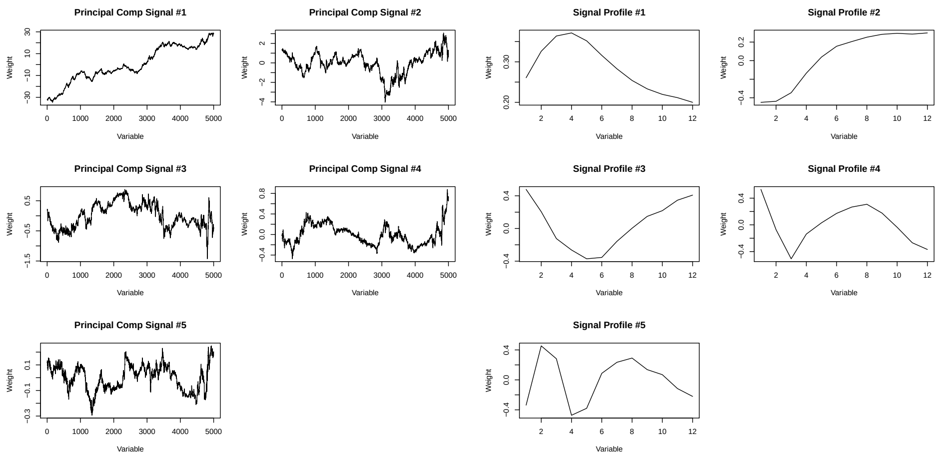

Figure 13: PCA 5-Dimensional Signal and Signal profile Plots.

In any case, the gain which is a bit less than 1% per year per contract. While this seems low, there are other reasons that this signal is untradable as it stands. First, trading two contracts a day to maintain a "constant maturity" portfolio is unrealistic. One would need to take the ups and downs in the equity curve (which are considerable, but below the resolution of the Figure) as an indication for a system that trades much less frequently. Second, there are long periods in which the trend makes no money. It would very, very important to identify conditions favorable to being long, being short and being out.

What we have done to this point in this article is perform curve-fitting. There was no rationale for the signals although the mistakes made in the original constant maturity approach were informative. In contrast, the next Section pursues a proactive program based on the Strategic Analysis of Markets Method (SAMM) of Moffitt (2017a), Chapter 11. We ask: Where might there be an edge, and how to perform analysis to investigate it?

5 Causes of Regular Patterns in Eurodollar Futures

Why should there be any favorable trading opportunities, whether arbitraged or not? And if there are such opportunities, where should we look for them? In order to identify such opportunities, it is important to discuss factors that affect strategies in credit markets.

5.1 Source of Arbitrage: The FED and the Spirit of the Times

WARNING: Some of the material in this Section requires a knowledge of how markets and banks operate, the history of regulation and politics. Opinions abound. Caveat emptor.

The organization that casts the longest shadow over worldwide credit markets is the U.S. Federal Reserve System (FED). Considerable insight into FED actions in recent times can be had by a brief review of its history. In 1907 the Knickerbocker Trust (a New York "hedge fund" of its day) was rumored to have suffered substantial losses from soured investments. Ironically, a postmortem on the Trust's finances revealed it was still solvent (Bruner and Carr (2008)). But the rumor was enough to ignite a bank run and in short order, the Trust and several other depository institutions halted redemptions. With the imminent threat of contagion, the retired J. P. Morgan returned to New York and bullied the banks into issuing a joint rescue of the Knickerbocker and other banks (Bruner and Carr (2008)). Luckily, that was enough to stem the tide.

But for Morgan and the New York banking community, it was clear that the U.S. needed a central bank in the European mold. A group of prominent bankers began meeting secretly on Jekyl Island to draft legislation, secretly because disclosure that the most powerful financiers were behind that legislation would probably kill it. By 1910 they sent a working draft to sympathetic members of Congress and worked behind the scenes to encourage its passage (Griffin (2010); Irwin (2013)).

By 1913, Congress was receptive to the need for a central bank that it hoped would prevent recurrences of the endemic credit panics of the nineteenth century. Its form, however, was hotly debated between conservatives, who wanted private banker control, and progressives, who wanted popular control. A compromise was reached in 1913 that created the FED. The structure has been durable; the FED is partly private, partly public, and is not part of, nor an agency of, the Federal Government. Conservatives insisted that it needed to operate without undue political interference, which they believed would render it ineffective. But progressives warned that structuring it as a profit-making enterprise would create a moral hazard: private profitability or public needs? Therefore, it was to be funded by Congress, but all its profits would be surrendered to the U.S. Treasury.

The legislation gave it three explicit mandates: (1) maintain maximum employment, (2) keep prices stable, and (3) maintain moderate long term interest rates. In 1913, though, it was not widely appreciated that these three are mutually incompatible. In fact, it was not until the mid 1930's that Keynes' famous treatise, "The General Theory of Employment, Interest and Money" Keynes (2006), clarified that incompatibility. The importance of the mandate problem is that the FED has always had to exercise judgment in setting priorities, requiring the favoring some parts of the mandate over others. It is probably underappreciated that policy setting is and always has been subjective, and in particular, heavily affected by the biases of its officers and the spirit of the times. But one thing is clear despite blurry mandates — it was created to bail out banks during financial crises, and to pursue policies designed to avoid having to bail them out in the first place. And in that mandate, it has been quite successful. But other priorities, e.g. full employment and defence of the currency, have not fared so well.

The FED has evolved considerably over the years due to the challenging situations it has faced. There has been a decade-long Depression, two world wars and numerous other military adventures, financial crises, and considerable banking legislation. All of these have modified its behavior, but we focus here only on the legislative dimension, especially in the 1930's, and in the 1980's and 1990's. But a fuller understanding of central banking is very important and I would recommend that anyone interested in a career in the markets study its history. The biggest part of that evolution has involved the tug-of-war between conservatives who want little governmental regulation of the private sector, and progressives who want "intelligent" regulation. Thus the Great Depression of the 1930's was believed to have been caused by excess speculation and weak banking regulation in the 1920's. As a result, heavy regulation of stock markets and banks was enacted during that decade as part of the New Deal. That system worked well until the stagflation of the late 1970's, when new theories of efficient markets counseled laissez-faire as a remedy to the problems of slow growth and inflation. Said the gurus: "Just produce a steady money supply and reduce regulation and markets will take care of the rest." And we'll all live happily ever after. Until 2008, however, when the fruits of that program finally ripened. Thus, in the two decades starting in the 1980's, most of the 1930's New Deal regulation was rolled back. Although a blow-by-blow account of the deregulation in this period is outside the present scope, there were milestones. These included elimination of the fixed commissions system for trading, increasing reluctance by the FED to regulate banking, introduction of derivatives, new laws and regulations that facilitated (legal) manipulation of corporate financial statements, repeal of Glass-Steagall, and the decimalization of the stock markets. It has been argued by many, many authors that the Global Financial Crisis of 2007-8 was largely due to the cumulative impact of this program of deregulation, although we won't repeat those arguments here.

But for system developers, there is an important question: Will the Global Financial Crisis of 2007-8 play a role like the Financial Crisis of 1907? Will it be a turning point, swinging the pendulum back toward more regulation? Inconclusive so far, but it is becoming increasingly clear that speculation in banking and shadow banking was a primary cause of the Global Financial Crisis of 2007-8. Recently, former FED chairman Ben Bernanke stated that more of the bankers should have been prosecuted. Few were (Page (2015)). Yet until relevant regulation is enacted and grows teeth, ours will be a future of recurring crises.

The foregoing discussion has consequences for trading system development, but those are likely to be slow-moving changes to the trading environment. Here are some possibilities. (1) There will be penalties for trading that is "potentially harmful to the market allocation function." By this, I mean that the proper role of investment and speculation is allocation of funds to the most promising enterprises; trading systems and instruments that do not promote this function are potentially at risk. I believe that there are two areas that are particularly vulnerable: high-frequency trading, and certain derivatives and trading practices using derivatives. For example, a properly designed transactions tax or the prohibition of rebates for "liquidity" would kill high-frequency trading overnight. Making derivatives that distort corporate financial reports illegal would reduce the off-balance sheet abuses. (2) Some version of Glass-Steagall may be reenacted. Reason: Keeping FDIC guarantees while allowing gambling creates moral hazard. That was a big reason for the Savings and Loan Crisis of the early 1990's, in which Savings and Loans were deregulated while keeping FDIC intact. But the problem today is not Glass-Steagall, per se, but the fact that deregulation has allowed bankers and shadow bankers to bet using money market funds, which is one reason that they pay somewhat better interest than bank accounts. But while money markets were guaranteed up to $200,000 in the Global Financial Crisis of 2007-8, there is no guarantee they'll be guaranteed next time. If we go there again, it's going to be a real mess.

The monetary policy of the FED is primarily determined by a presidentially-appointed *Board of Governors* (FRB) that serve 14 year terms, and secondarily by officials of the twelve regional FED member banks and a *Federal Open Market Committee* (FOMC) that buys and sells Treasury instruments to expand or contract the money stock. At this writing, there are 5 Governors with two vacancies due to political deadlock. Appointees are mostly economists and bankers who have one foot in academics or banking and the other in politics. As such, policy is set by the politically connected people on the board, and therefore the prevailing consensus in economics has great impact on policy. Remember Keynes' insight:

> The ideas of economists and political philosophers, both when they are right and when they are wrong, are more powerful than is commonly understood. Indeed the world is ruled by little else. Practical men, who believe themselves to be quite exempt from any intellectual influence, are usually the slaves of some defunct economist. Madmen in authority, who hear voices in the air, are distilling their frenzy from some academic scribbler of a few years back. I am sure that the power of vested interests is vastly exaggerated compared with the gradual encroachment of ideas.
>
> John Maynard Keynes, "The General Theory of Employment, Interest and Money," Keynes (2006), page 383.

But there is one important characteristic that all Board members share — an aversion to risk-taking. They are poor gamblers, and that leads to poor policy.

Now to the point — why would the FED create trading opportunities? There are two reasons: (1) their actions are largely predictable, and (2) in some cases, they intentionally "give away money." Regarding (1), the FED in recent years tries to change policy gradually and with plenty of warning. The cadre of "FED watchers" that hang breathlessly on every nuance of FED-speak ordinarily forecast the immediate future quite well, which reminds me of the story of the Oracle at Delphi. In Ancient Greece, the Oracle (a priestess) was widely sought by wealthy patrons for her powers of divination, which rumor has it, were delivered in a frenzy induced by vapors emanating from a fissure in her chamber ... and while her utterances seemed gibberish to the uninitiated, they were perfectly clear to the priests who accepted donations for translating ... In general, the intermediate direction the FED intends is not in dispute, only the timing. Regarding (2), all central banks routinely give away money, but sometimes more than they expect. Unlike most other central banks, though, the FED typically does not defend the currency. In an episode that shows the folly of defending a currency and which made George Soros famous, his Quantum Fund made a $1 billion Pound Sterling bet against the Bank of England in 1992 — and won due to the Bank of England's futile attempt to defend the Pound. Incidentally, Soros made sure other currency speculators got the message; he broadcast loudly that the BofE's defence was futile. The FED, during the entire period from 2007 to 2015 (the time of this writing) has engaged, predictably I would argue, in a hyper-expansionary monetary policy to combat a period of slow growth. The impact has been, again predictably I'd argue, to line the pockets of the banks and the wealthy, but not reflate the economy as was intended. Thus the hard money gurus have been completely wrong – inflation is not the problem — deflation is. Please realize that I do not mean these comments as criticism, just as my views on the way things work.

Here are my views about the FED — take them with a grain of salt. First, when the FED policies are divergent from the market, bet on the market. Today (October, 2015) the FED is telegraphing a rate hike, and the market has signalled opposition. Second, be sensitive to the Zeitgeist, and understand the big picture impact of FED policy. For me, the major impact of that policy is whether it encourages speculation or not. The consensus postmortem analysis of the FED's actions in the 1930's is that they erred in maintaining tight monetary policy. But Alan Greenspan has been criticized for ignoring his regulatory authority in the lead up to the Dot-com Bubble (failure to pursue counter-cyclical monetary policy, despite his famous "irrational exuberance" remark). Eventually, the FED, and the no-regulation Zeitgeist will be blamed for the Global Financial Crisis of 2007-8 (no mortgage market regulation). And as of this writing, the FED still seems to be in the thrall of conservative economics, reluctant to exercise its regulatory authority. What this will encourage, I believe, is continuing crises and continued short term trading opportunities. And this means that short-term trading systems will be viable for a while longer.

5.2 Source of Arbitrage: Segmentation that Causes Yield Curve Patterns

A second reason for arbitrage opportunities is *segmentation* in the yield curve. This mechanism posits that different players inhabit different parts of the curve. Front end players typically have short-term financing needs or are arbs, while back end players are hedgers, investors and arbs. They certainly have different financing and investing needs, if not different views about the prospects for the economy. It is not unreasonable, then, to believe that their actions could have some element of predictability based on slowly-moving economic factors.

As the Global Financial Crisis showed, the modern economy cannot function without short-term credit markets. If the mortgage markets that initiated the crisis hadn't spread to the short-term credit markets, the worst of the meltdown would have been avoided. In strategic terms, then, it is worth knowing the reaction of markets since the crisis, especially the demand at the front end of the yield curve.

I have no compelling answer to this question, but there have been a couple of developments that are important. First, in the aftermath of the Crisis, companies began building war chests to avoid over-reliance on short-term funding. Second, some of the short-term funding has been been moved further out on the curve because of near zero rates at the front end. Therefore, another credit crunch like the one in 2007-8 seems less likely. This is a general rule — history doesn't repeat itself, but it rhymes (unsourced saying). The coming crises will probably not involve credit markets directly, but will involve leveraging or deleveraging in markets. My guess in late 2015 — purely a guess — is that equity markets will deleverage over a period of time, not crash suddenly. And that will spawn "little bubbles" in other markets as money seeks opportunity ...

5.3 Source of Arbitrage: Event Plays

There are regularly-scheduled events in the credit markets that might be used to develop trading systems. Some candidates: (1) treasury auctions, (2) regularly-scheduled FED meetings, actions and testimony, and (3) futures and options expirations. In Section 6, we introduce a study of expiration events in Eurodollar futures, and investigate a PPGS. An old method in a new guise will be introduced to analyze event data.

But to the extent that generalization is possible, events are of several types, two of which are identified here: (1) suspense-surprise, and (2) rumors. Suspense occurs when the timing of an event is known and the risks are well-known. Unless the deviation from expectations is large, this type of event has little impact on long term prices. But in the immediate aftermath of an unremarkable suspense event, there is often a transient *overreaction* which has the appearance of a liquidity-driven reaction, since for suspense events, traders (and especially market makers) withdraw bids and offers in order not to have "single event" risk. But for remarkable suspense events and surprise events, there is generally an *underreaction* and this type of event is usually tradable on longer horizons. Examples: the reactions to Standardized Unexpected Earnings (SUE's) (surprise) presented in Section 5.5.4 of Moffitt (2017a), and the reaction to the 9/11 attacks (surprise), which caused a 5.07% drop when the market reopened on September 17, and bottomed out down 17.8% on September 24.

The second type is a "rumor event." There is an old trader's saying: "Buy the rumor, sell the fact." As usual, this adage contains a grain of truth, but it is not nuanced enough to be useful. Here is what I'd say. If you know you're near the origin of a rumor, trade. If not, ignore it — you're probably too late to profit.

5.4 Source of Arbitrage: Inefficient Forward Markets

Another reason for arbitrage opportunities is that systems are known to have beaten interest rate markets in the past, e.g. riding-the-yield-curve.

6 Analysis of Eurodollar Rolls

We now introduce a method for analyzing financial event data (Ramsay and Silverman (2005, 2007)) illustrated in this instance by Eurodollar expiration prices. We begin with a description of how to construct an "event dataset."

6.1 Constructing a Dataset for Event Analysis

In this section, we construct a dataset of "events" to study their impact on a dataset of market prices. With this in mind, let $X(m \text{ x } r)$ be a matrix dataset with m "event rows" of length $r = p+q$ with $p \geq 2, q \geq 2$, each row having p prices and q other variables. The prices come from a time series Y of J instruments. Some of these instruments can contribute multiple rows of p prices to X. A particular $j \in J$ contributes an "event vector of prices" at time t_0 only if an event that is hypothesized to affect j occurs at t_0; in that case a p-vector is formed having l prices before t_0, and u prices after. Thus with $p = l + 1 + u$, the p-vector contributed by j has the form

$$\underbrace{(x_{t_0-l,j}, x_{t_0-l+1,j}, \ldots x_{t_0-1,h}}_{\text{l times}}, x_{t_0}, \underbrace{x_{t_0+1,j}, x_{t_0+2,j}, \ldots, x_{t_0+u-1,j}, x_{t_0-u,j})}_{\text{u times}}$$

In order to enforce uniform labeling of *event time*, each event's prices are assigned relative times $-l$, $-l+1$, ..., -1, 0, $+1$, $+2$, ...u. Only 2 other variables are required to be among the $q \geq 2$: (1) j, the instrument that generated the event, and (2) the time t_0 (which is no longer available because it was replaced by *event time*).

It is useful to discuss some examples of event datasets in order to indicate important variations. Consider for example, a "stock split event dataset," assembled to determine if there are persistent moves that occur prior to or after a split. Let Y be all stocks in the Russell 2000 stock dataset from January 1, 1980 to the present, with t_0 the dividend announcement date and an *event window* with $l = 62$ and $u = 126$. The choice of l and u may seem odd, but 63 is the approximate number of trading days in a quarter, and 126 the approximate number in 2 quarters (There are quarterly cycles in stocks, but this article doesn't discuss them). Furthermore, there is no harm in selecting overly wide *event windows* which can be restricted later during an analysis. In addition to the stock and split announcement time, we might want to include as other variables the split fraction *a*:*b*, the stock Size (Small, Medium, Large) and the Book-to-Market Ratio (High, Medium, Low). The reason for inclusion of the last two variables is that they are part of the Fama-French 3-factor model as discussed briefly in Example 11.2.5 of Moffitt (2017a) and in more detail in Section 18.7.4 of Moffitt (2017b). It might be advisable to use the ratio of a stock's price to the S&P 500 on each day or some other model of "fair" price (see reference Campbell et al. (2012), Section 4.3, pages 153-7) instead of its actual price.

Here is another example. Let Y be a dataset of mutual funds that existed during the period from January 1, 1990 to the present, regardless of whether they existed on January 1, 1990 or still exist. The event in this case is the date that each fund releases its quarter-ending statement (if it reports quarterly), a *type 1 event*, and the last trading day of each quarter, applicable to all stocks, a *type 2 event*. The purpose of this dataset is to study market reactions to mutual fund statements releases, and to determine if there are quarter-end patterns in pricing. It is known that many funds "window dress" their portfolios prior to reports in order to hide embarrassing investments, making it possible that changes in fund price might be associated with such end of quarter selling. One possible choice of the event window would be $l = u = 31$. Besides the two required variables and the row event type (1 or 2), variables that describe the fund's classification, stock market volume and the one year market return might also be added. In the analysis phase, event type 1 records could be selected for one type of analysis, and event type 2's for another.

In the split example, there was no synchronicity; in the mutual fund example, large numbers of type 1 events will occur near quarter end, and all type 2 events will occur at quarter end. In the *Eurodollar Futures Expiration Event Dataset (EFEED)*, there is complete synchronicity and an additional complication — highly correlated instruments along the curve. These matters are discussed next.

6.2 The Eurodollar Futures Expiration Event Dataset

We call attention again to our abuse of terminology; Eurodollars futures are actually like forward contracts on 3-month Eurodollars, so we are analyzing the spot rate curve, not the yield curve. Nonetheless, we'll commonly refer to these as analyses of the "yield curve."

For the analysis of Eurodollars, we select a dataset of the leading 4 quarterly Eurodollar futures. Daily prices are available on all 4 contracts on every trading day from April 2, 1982 to July 22, 2008. Quarterly expirations occur on the Friday preceding the third Wednesday of March, June, September and December, so there are 4 event dates per year, the number of instruments on each of these days is $J = 4$. Recall that we hypothesize some nonrandom pricing behavior prior to and perhaps after these expirations because of *price pressure* resulting from rolls. The problem, though, is that the net roll can either sell the leading contract or buy it, and it is unclear which is occurring from mere daily data. Therefore, there is no a priori pattern we can assert, but we do *know* that lots of traders will need to roll out of the leading contract before expiration.

We use $l = 41$ and $u = 21$ so that the event window has 63 trading days, which just happens to be the approximate number of trading days between quarterly expirations. The reason for this choice is that the event dataset will be constructed from (almost) non-overlapping time windows, eliminating the possibility of spurious correlations. A problem, however, consists of how to handle the leading contract of the 4, since it will have full history prior to the expiration but none after. Our choice is to let the first contract of the event dataset be the one with about 5 months of life remaining and follow it for the next 63 days, up to the point at which it has about 2 months of life remaining. We label that Contract 1 in the event dataset. Contract 2 is the next contract, starting with about 8 months of life remaining, etc.. The rationale for choosing $l = 41$ and $u = 21$ is that contract 1 will begin "feeling the pull of the coming expiration" at some point. We therefore opt to follow that contract for only the first month (21 days) of its remaining (approximately) 63 day lifespan. This dataset has a property we need — comparisons between prices in a row are between the same contract, not different contracts. While there may still be distortions induced by nearness to expiration, our hope is that they are not serious.

The dataset so constructed has 108 expirations with 3 rows per expiration (since the leading contract of the original dataset is dropped), leading to an X matrix of dimension 324 x 65. The zero event time of X occurs on the 42^{nd} column. The column dimension (65) is due to the $p = 63$ prices plus the contract number and the expiration date t_0. We will refer to X so constructed and the *Eurodollar Futures Expiration Event Dataset (EFEED)*, with the understanding that the first 63 are Eurodollar prices, the next column is the contract, and the final column is the expiration date.

The first six rows of the EFEED dataset having the 1^{st}, 2^{nd} and 3^{rd} EFEED contracts is shown below in two sections. The top section has 42 columns corresponding to pre-expiration and expiration, and the lower section the other 23 columns. The final column (*Expir*) has the expiration date, and the next to last column (*ContrIndex*) the position of the futures contract, 1 being the first, 2 the one expiring three months later and so on. The top row has prices for *ContrIndex* = 1, with column *DAY.0* having the price for expiration day *1982-06-14*. The columns *DAY.m41* (the 'm' stands for 'minus') is the day 41 trading days before expiration, which for the first row is *1982-04-29*; the last day, 21 days after expiration in the column *DAY.p21* (the 'p' stands for 'plus') is *1982-07-28*. Similar calculations apply to the other expirations. Obviously, many days are omitted in this sample of the data. Altogether, there are 108 expirations, thus 324 rows.

```
DAY.m41 DAY.m40 DAY.m39 ... DAY.m21 ... DAY.m2 DAY.m1  DAY.0
  84.80   85.00   85.19 ...   85.66 ...  84.98  85.13  84.57 ...
  84.90   85.04   85.19 ...   85.63 ...  84.89  85.05  84.52 ...
  84.90   85.00   85.18 ...   85.60 ...  84.89  85.03  84.51 ...
  85.08   85.46   85.48 ...   85.89 ...  86.64  86.03  86.34 ...
  85.14   85.52   85.49 ...   85.78 ...  86.30  85.72  85.97 ...
  85.16   85.57   85.50 ...   85.75 ...  86.33  85.78  85.93 ...
   ...     ...     ...         ...        ...    ...    ...

 DAY.p1 DAY.p2 ...  DAY.p20 DAY.p21 ContrIndex      Expir
  84.56  84.51 ...    84.93   84.87       1      1982-06-14
  84.54  84.51 ...    85.00   84.90       2      1982-06-14
  84.54  84.53 ...    85.05   84.95       3      1982-06-14
  86.46  86.28 ...    90.11   90.00       1      1982-09-13
  86.02  85.80 ...    89.38   89.29       2      1982-09-13
  86.05  85.80 ...    88.99   88.96       3      1982-09-13
   ...    ...          ...     ...        .         ......
```

Figures 14, 15 and 16 have 63 day plots for all 108 expirations. Each plot has three vertical lines, the leftmost about a month before expiration and the rightmost the expiration time. Can you see any pattern to these plots (Hint: There is one.) It is not easy visualize, much less test, data in this format. But the data is in the best format to discover any patterns that exist, preparing the way for the statistical analysis of the next section.

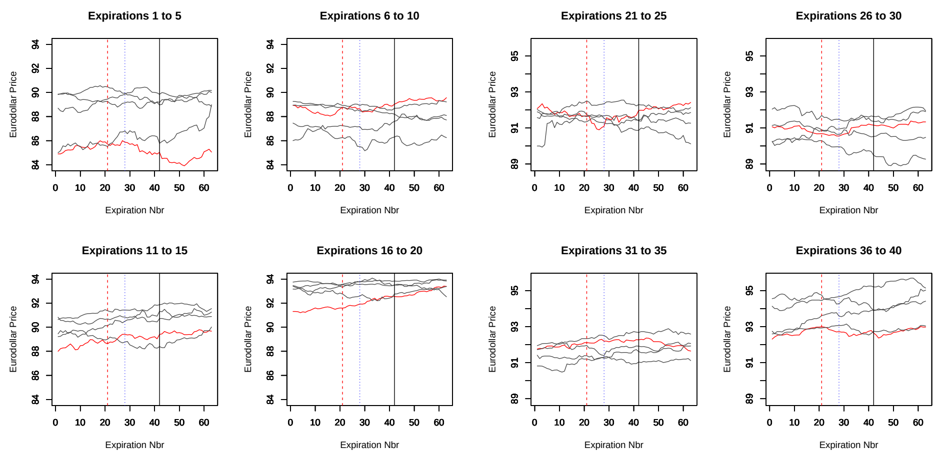

Figure 14: The left panel shows 63 day price plots for the first 20 expirations, and the right for the next 20.

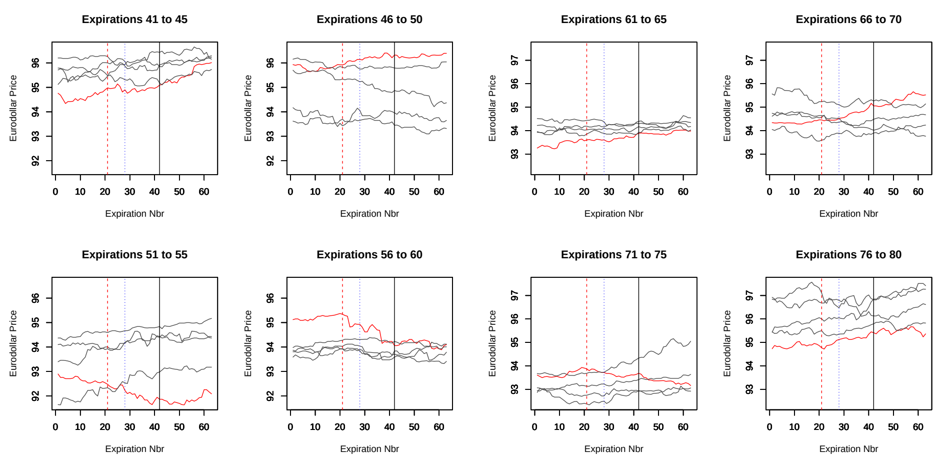

Figure 15: The left panel shows 63 day price plots for expirations 41-60, the right for expirations 61-80.

6.3 Statistical Analysis of the Event Dataset EFEED

The analyses we'll perform are designed to discover patterns that exist prior to and/or after expirations, and that is the reason that the event form EFEED was chosen. We generalize and enshrine the underlying principle as

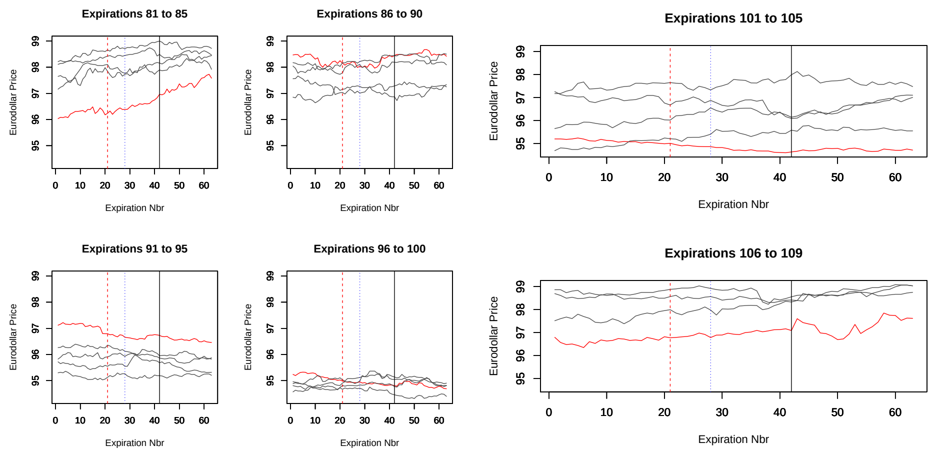

Figure 16: The left panel shows 63 day price plots for expirations 81-100, and the right for expirations 101-108.

> **SYSTEM DEVELOPMENT PRINCIPLE #3**:
> Design your datasets to make it easy to discover the sought-after patterns. A poorly designed dataset can obscure important patterns.

6.3.1 What We're Looking For

How can the EFEED format be used to discover expiration trading patterns? To begin with, we hope that expirations are heterogeneous; if a simple pattern were to exist, it is already likely to be arbbed out (recall that there are no significant limits to arbitrage in Eurodollar futures markets). If this is the case, average behavior in and of itself might be unhelpful — we'd prefer instead a characterization of, say, k expiration patterns, some of which can be predicted. Furthermore, we do not require that regular patterns span the entire period of 63 days — it is enough that they span only a few days. We'd also guess that patterns in and around the expiration date would show patterned behavior. But a pattern's span should be more than a few days because myopic market makers would be likely to pick up on those patterns. Here, then, are some guidelines for the analysis

1. Look for pattern heterogeneity.
2. Ignore averages.
3. Look for subpatterns that don't span the entire 63 days.
4. Emphasize search within a few days of the expiration.

Before beginning the analysis, an important aspect of Eurodollar trading needs to be discussed — market maker arbitrage. Recall that market makers are short term traders that rely on leverage to carry large positions with small edges; they are therefore sensitive to small price changes. In the Eurodollar futures markets, market makers who "trade size," meaning that they make large, presumably highly leveraged trades. do not want to make pure bets on the direction of rates. Therefore, when an order arrives, the first thing market makers try to do is hedge it with another contract: e.g., if the order is to sell *Jun*, a market maker might buy *Jun* and sell *Sep*. Also possible is buying *Jun* and selling *Dec*, but ceteris paribus, that spread has greater risk — the "go-to" spread is *Jun-Sep*, mitigating circumstances notwithstanding. Spreads offer some protection against rate changes, but also give market makers an incentive not to let those spreads move against them. As usual, an imbalance can be on either side of the spread, but if many of the slower-trading players place orders at about the same time on the same side of a contract (very common), it can cause a temporary (or maybe permanent) bulge or dent in a contract's price. So here we see a possibility that is informative because unusual buying activity in *Jun* may beget unusual selling activity in *Sep*, often without moving the spread too much. One consequence is that market maker distress is probably indicated more by spreads than rates. And incidentally, there is a general principle here. If two instruments are used as hedges against each other in a popular arbitrage, a move in one tends to be followed by an opposite move in the other. Furthermore, an unusual move in one is likely to have "ripple effects" on others. This discussion suggests two more guidelines:

(5) Unusual moves in a contract may have ripple effects.

(6) In Eurodollar futures analysis, spread price changes may indicate market maker distress.

Of course, since our observations are daily, an imbalance is probably quite large if we can detect it in closing prices.

6.3.2 How to Extract Principal Component Factors

A principal components analysis (PCA) on the EFEED dataset might reveal patterns around expirations. For simplicity, we examine only contracts 1, 2 and 3 in the analysis, and call the dataset restricted to these three EFEED-3. Since there are 108 expirations, the EFEED-3 will have 324 rows. Figure 17 is a plot of all three contracts. The top panel shows the three Eurdollar contracts in positions 1, 2, and 3 of the EFEED-3 dataset, with the x-axis being the expiration number (1-108) and the left axis being the Eurodollar contract price. The contract spreads are so small that the curves can be distinguished only in a few places. To emphasize the correlation, the middle panel "jitters" the prices, subtracting 0.5 from contract 2 and 1.0 from contract 3. That is enough to show the curve's separation, while maintaining the order of contract prices, the top being contract 1 and the lowest contract 3. The lower panel has the *median absolute deviation* of the two spreads, defined for random variables x_1, x_2 as

$$mad(x_1, x_2) = 1.4826 * |x_1 - median(x_1, x_2)| = 1.4826 * \frac{|\, x_1 - x_2 \,|}{2},$$

The normalization by 1.4826 makes $mad(x_1, x_2)$ unbiased for σ when $x_1 - x_2 \sim N(\mu, \sigma^2)$. In this case, the *mad* is proportional to the standard deviation with $n = 2$. But when $n > 2$, the *mad* give less weight to outliers than the standard

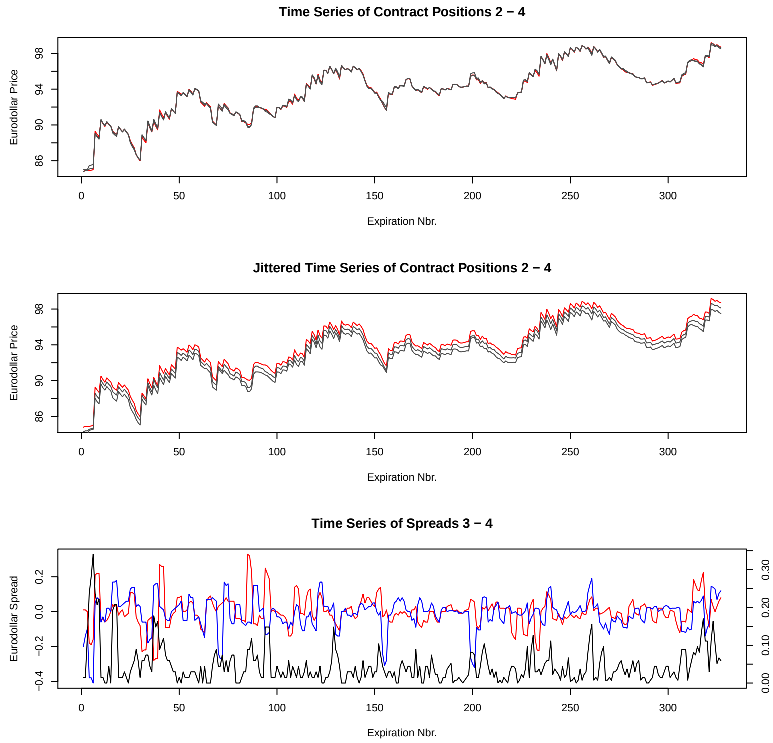

Figure 17: The top panel has a plot of prices of contracts 1, 2, and 3 at expirations only, joined by straight lines. On the scale of the plot, with Eurodollar prices ranging from about 85 to 99, the three contracts cannot be distinguished. The middle panel "jitters the contracts" by subtracting 0.5 (a large value in these contracts) to allow them to be distinguished. Contract 1 is uppermost and Contract 3 lowermost. Although only expiration day prices are shown, the correlation of these contracts is obvious. The lower panel plots the 1-2 spread and the 2-3 spread as the upper lines. Note that spreads don't have the strong correlation of prices. The lower line with "spikes" is the *median absolute deviation* between the two spreads.

deviation. It is generally preferable to the standard deviation when descriptive statistics, not hypothesis testing, is the goal. Note that many spikes, i.e. *mad*'s that are large compared to neighboring *mad*'s, occur near tops and bottoms. We warn that visual extrapolations such as this can be quite misleading, and in any case, no test of this idea will be undertaken.

Figure 17 raises an important question about what we want to accomplish with a PCA. Our initial analysis is intended to identify any *shape* patterns in the 63-day period surrounding an expiration. Because of the large range of Eurodollar prices in the Figure, the shape may vary with the price level, in which case an analysis of an EFEED *price* dataset may be inadvisable. Therefore, we will transform rows of the EFEED dataset to "shapes" and then apply a PCA to that matrix.

6.3.3 Principal Components on a Shape EFEED-3

In designing a shape statistic for 63-day vector of prices $(y_1, y_2, \ldots, y_{63})'$, we wish to remove dependence on the level of prices y_i. That can be accomplished in many ways, but we use a transformation

$$shape : \mathbb{R}^n \to \mathbb{R}^n$$

that has three properties: (1) the sum of elements of $shape(y)$ is zero, (2) their absolute sum is 1, and (3) $shape(y) = shape(ay+b)$ for any real numbers $a > 0, b$. The unique transformation with these properties (provided y is not proportional to a vector of all 1's) is

$$\begin{aligned} shape(y) &= \frac{1}{cad(y)}\,(y - \bar{y}1_n), \qquad (2)\\ \bar{y} &= \frac{1}{n}\sum_{i=1}^{i=n} y_i,\\ cad(y) &= \sum_{i=1}^{i=n} |\, y_i - \bar{y}\,|. \end{aligned}$$

where 1_n is a vector of n 1's. Note that (2) uses the cumulative absolute deviations as a denominator, not the standard deviation. This produces variables that sum to zero and are scaled around 0, some being above and some below. And of course, using the notation $shape(y, i)$ for the i^{th} rescaled y_i, the sum of absolute $shape(y, i)$'s is 1.

Earlier inn Sections 3 and 4, the dangers of using an untradable signal were discussed, including possible artifacts in the analysis due among other things, to lookahead bias. If we simulate trading by using the *shape* statistic, our signals will surely be untradable because of a lookahead bias! However, we're doing this analysis to determine if there are any price patterns in the 63 day period by centering and rescaling with *cad*. We cannot use *shape* as a tradable quantity, because it is not tradable, but our hope is that it will inspire a real trading system if salient shapes emerge.

We prepare an EFEED-3 *shape* dataset, EFEED-3S, as follows. In each row of the EFEED-3 dataset, we perform the transformation (2) of the 63 prices, and substitute these for the actual prices, leaving the last two variables unchanged. The analysis below is restricted to contract 3.

We now present the results of performing a PCA analysis on the EFEED-3S dataset. The eigenvalue histogram is shown in Figure 18. Note that each bar of the histogram has data from about 6 signals. The first four signal variances account for about 75% of the variance:

	PC1	PC2	PC3	PC4
Standard deviation	1.4247	0.7776	0.63889	0.52251
Proportion of Variance	0.4596	0.1369	0.09241	0.06181
Cumulative Var. Prop.	0.4596	0.5964	0.68885	0.75066

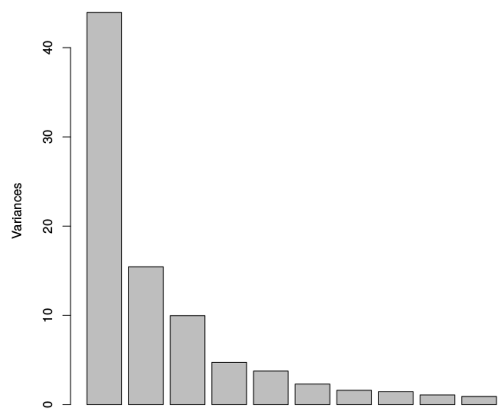

Figure 18: PCA Eigenvalue Histogram For The Shape Transformation.

Refer now to Figure 19, which has 4 signals in the left-hand panel and 4 signal profiles in the right-hand panel. The regularities of the profiles is really quite impressive! Recall that day 42 is expiration day, with the plots covering a period from about two months prior to expiration to one month after. The *shapes* in each row were determined from the EFEED Contract 1. Therefore, all prices in each row are comparable in the sense that they arise from a single contract, no splicing being necessary.

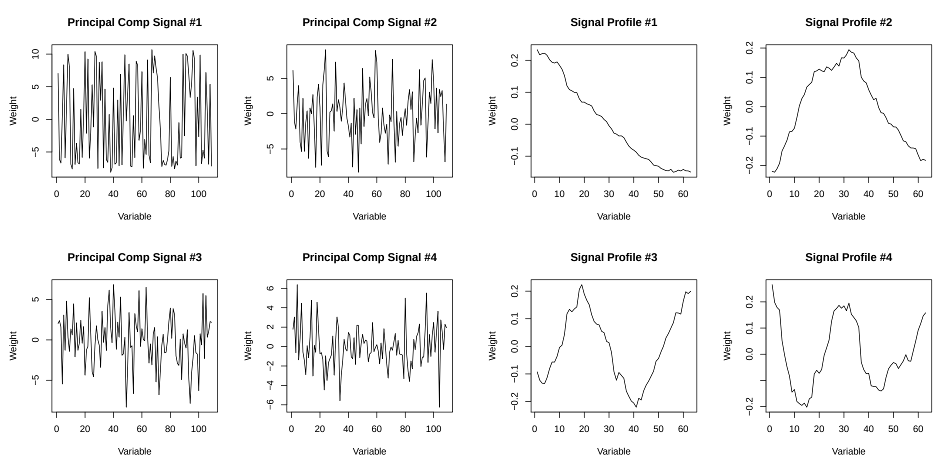

Figure 19: ICA Left Panel: Signal plots for the first 4 signals. Right Panel: Signal profiles for first 4 signals.

First, note that the dominant signal shown in the northwest corner has about 46% of the variance and is mostly linear except for the last 2 weeks or so. Second, recall that a PCA analysis centers all variables and signals so that the 0 value on the y-axis has no meaning in terms of the *shape* variable, except as an indicator that it's above or below its average for the period. Since negative signal profiles (eigenvectors) are as likely to occur in a principal components analysis as their positive counterparts, the graph could as easily be descending as ascending, as it would be with a rotation around the horizontal axis. It is important to investigate the centering further, since time series effects might be detected. This is a simple matter; we calculate the column means for the 63 shape variables and plot them in Figure 20.

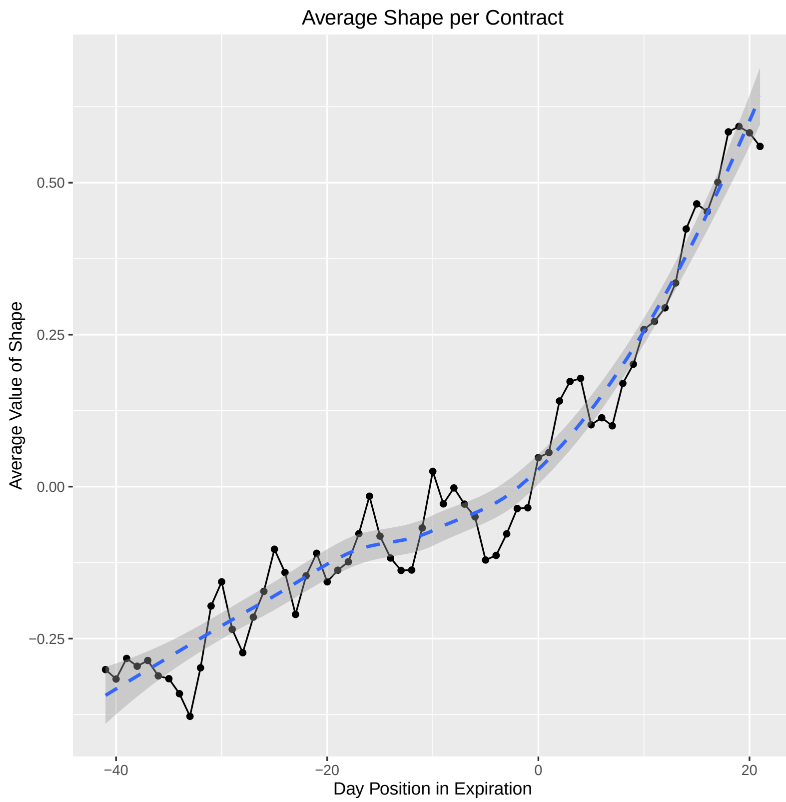

Figure 20: Average shape for contract 4 dataset EFEED-3S.

Note first that the ascending trend in the *slope* variable is hardly surprising since since short end rates over the sample period moved from around 15% to less than 1%. Recall that in the PCA algorithm, this trend is subtracted from prices as part of the covariance calculation. But this obscures two important things: (1) the ascending pattern in the *shape* variable, and (2) the distinct change in curvature before and after expiration, exactly the effect we are looking for. We will remedy these problems below, but it is nonetheless worth examining the signal profiles of Figure 19 first.

In the dominant signal in the upper northwest corner of the right-hand panel of Figure 19 we see a linear profile until about the last two weeks. It is not clear what that flatness represents, although it might indicate the end of an expiration rollover impact. The profile of the second principal component, signal

2 in the northeast corner of Figure 19, accounts for 13.7% of the variance and has a suggestive shape. It shows movement in one direction (up or down) for the first 3 weeks or so (up to day 17), a slower move in that direction for the next 3 weeks (up to day 32) followed by a reversal (down or up) from about 2 weeks before expiration to 1 month after (day 32 to day 63). The profiles of the third and fourth principal components, signals 3 and 4, show distinct reversal points at around day 15-18, day 32 and day 42.

Let us put these results in perspective. Approximately the same turning points in signal profiles of PCA shape signals 2-4 occur around days 17, 32 and 42. The pattern of any particular expiration will be a superposition of these profiles, weighted by the value in the signals themselves and with the mean curve 20 added thereto. But if there is a rollover effect, one should examine the returns between these points, as we do below.

6.3.4 A Within-Expiration Trading System Based on EFEED-3S PCA: 1982 - 2008

As stated previously, results from the EFEED-3S shape analysis are not directly translatable into a trading system, since shapes, among other things, suffer from a lookahead bias. The real value of those results must involve development and testing of a PPGS, which we now undertake.

Figures 21, 22 and 23 were performed on a centered EFEED-3 denoted by EFEED-3C. That dataset is constructed from EFEED-3 by subtracting from each row of prices its mean; thus the rows of EFEED-3C consist of price deviations from the mean (and therefore sum to zero). This transformation doesn't affect a *within-expiration* analysis of trading gains since differences in actual prices will be the same as differences in centered prices. This article uses only gains, not returns.

The left panel of Figure 21 shows a scattergram of gains in the first 17 days of the 63 day window vs. the gains in the next 14 days, with the solid line a least-squares regression and the dotted line a loess smoother. Both indicate that these gains are positively correlated, which indicates that a system that trades the 17-32 period using the sign of the 1-17 day period might be profitable. Moreover, the gains are not trivial, with the second period gaining about 30% of the first. There are some problems with this graph, since the large range of interest rates (1% to 15%) may make gains in the high rate portion look like outliers in the low rate portion. This problem is investigated below. Similar remarks apply to the right panel graph of days 17-32 vs. 32-42.

Figure 22 investigates the period 32-42 vs 42-52 in the left panel, and 42-52 vs 52-63 in the right panel. There appears to be no relation between the 10 days prior to expiration and the 10 days after (left panel), but there is a predictive relation ship in the right panel. Note in the right panel the smaller variability in the 52-63 period vs the 42-52 period. The edge in this case might be too small to trade.

Figure 23 plots the pre-expiration 1-17 period vs two post-expiration periods. There is no useful information in these plots.

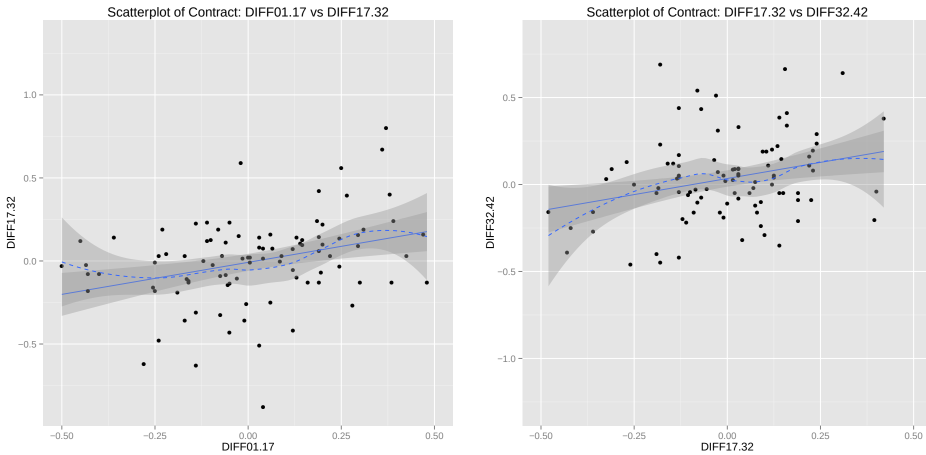

Figure 21: Trending relationships in the EFEED-3C period from day 1 to day 42.

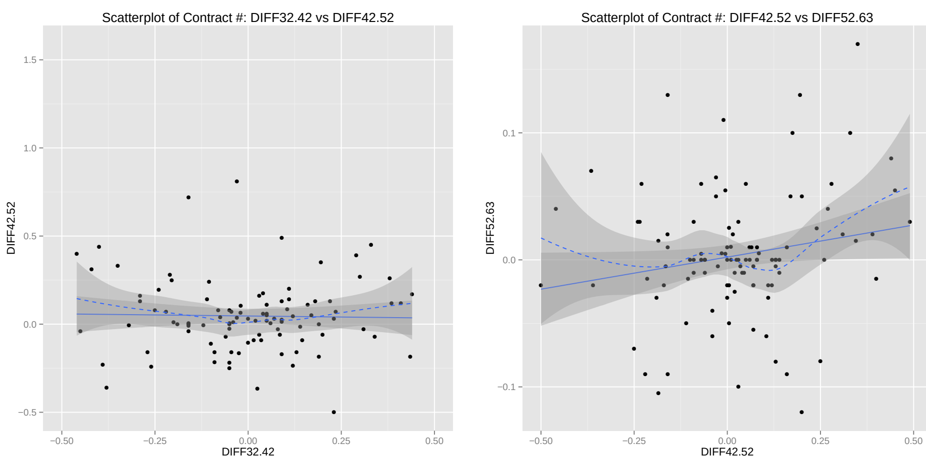

Figure 22: Trending relationships in the EFEED-3C period from day 32 to day 63.

Based on the relationships in Figures 21 (both panels) and 22 (right panel), we now investigate the PPGSs they suggest. The left panel of Figure 24 shows the time series of cumulative gains from buying (selling) day 17 when the gain from period 1-17 is positive (negative) with automatic exit on day 32. The right panel shows the cumulative gains for the strategy of buying (selling) on day 32 when the gain in period 17-32 is positive (negative). Both these graphs show at least two regimes, the pre-1990 high rate regime and the lower rate post-1990 regime. Similarly, Figure 25 shows that cumulative gains for 32-42 $\rightarrow$ 42-52 in the left panel and 42-52 $\rightarrow$ 52-63 in the right panel. These relationships do not seem tradable.

Therefore, we now restrict the analysis to the period from 1990 to 2008.

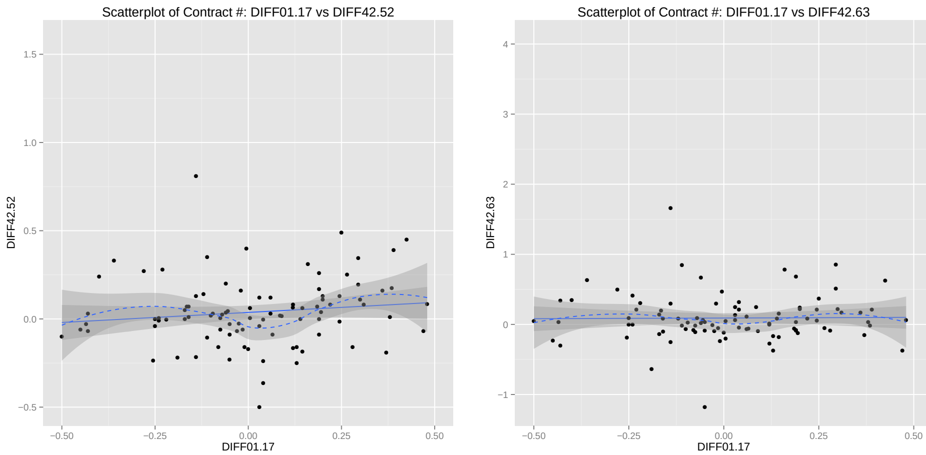

Figure 23: Trending relationships in the EFEED-3C period from days 1-17 to days 42-63.

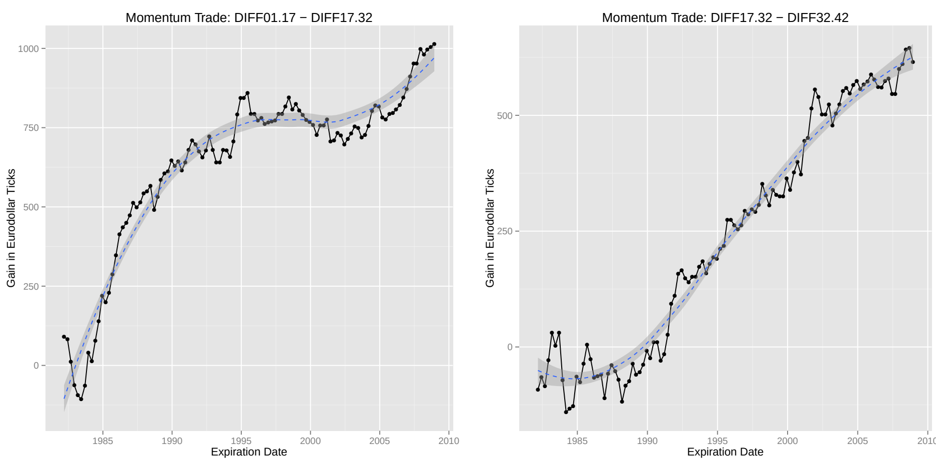

Figure 24: Profits & Losses. Left Panel: 1-17 → 17-32. Right Panel: 17-32 → 32-42.

6.3.5 A Within-Expiration Trading System Based on EFEED-3S PCA: 1990 - 2008

This Section performs analyses similar to those of the 1982-2008 period. Three month Eurodollar rates in 1990 occurred after the stagflation and high rates of the 1970's and and the lower rate environment of the 1980's. The period since 1990 has been one of lower rates, the majority of the time 6% or less. Because of these lower rates, we move out on the curve and examine the 3 EFEED contract that corresponds to the 1 year, 9 month-after-expiration Eurodollar contract.

Figure 26 has the shape column means for this period, quite similar to those of Figure 20.

The signal profiles for the PCA analysis of the period 1990-2008 is shown in

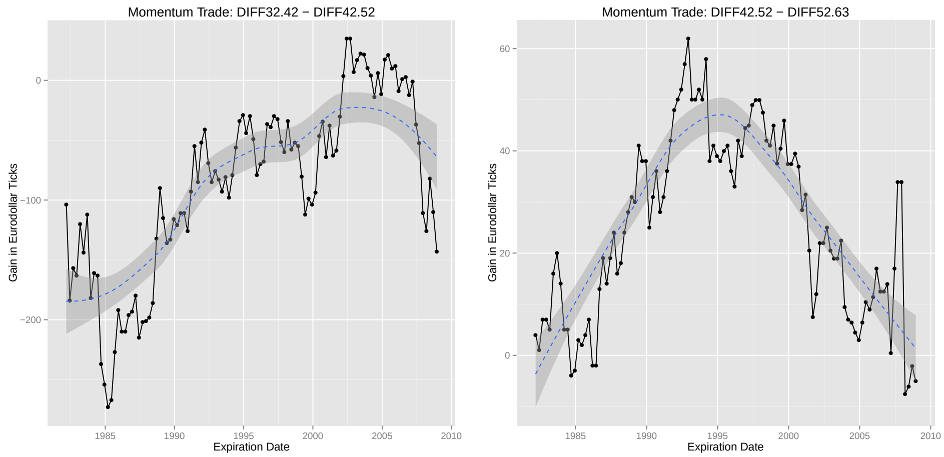

Figure 25: Profits & Losses. Left Panel: 32-42 → 42-52. Right Panel: 42-52 → 52-63.

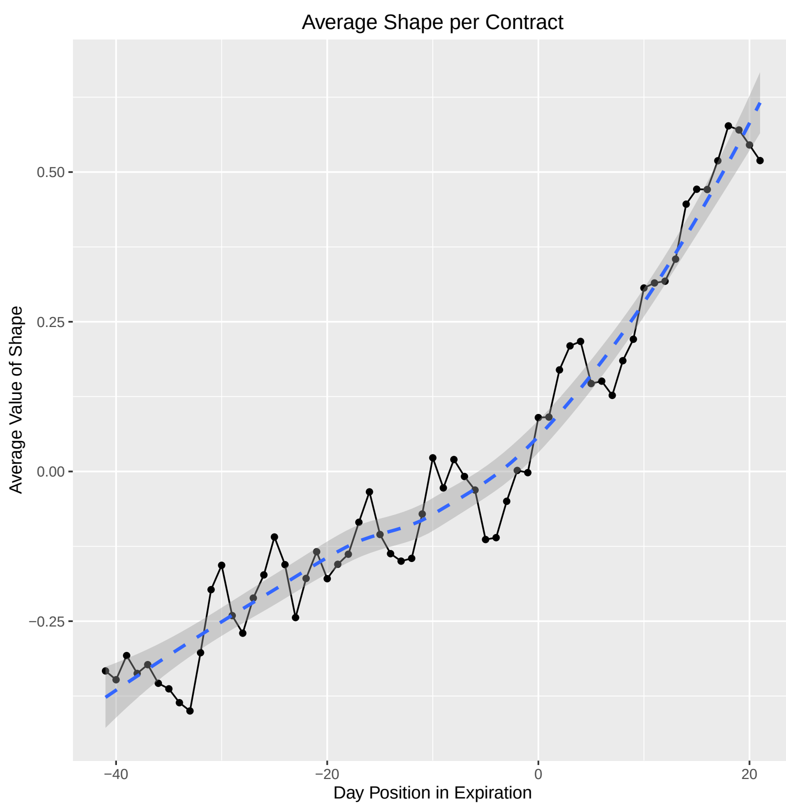

Figure 26: Average shape for contract 2 in dataset EFEED-3S: 1990 - 2008.

Figure 27. The shapes of these plots and their turning points are quite similar to those of Figure 19.

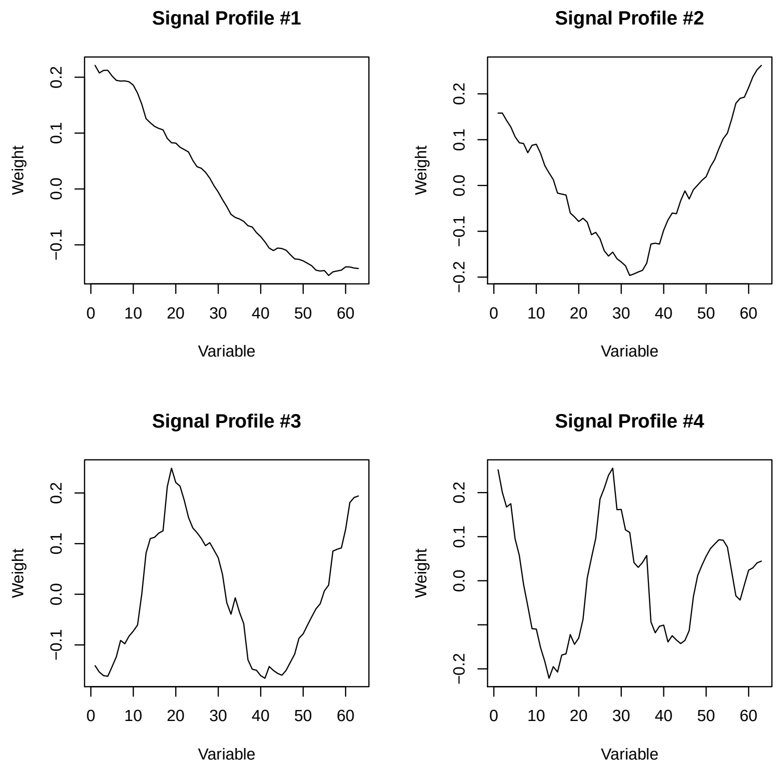

Figure 27: PCA Analysis for the Period 1990 to 2008.

Figures 26 together 27 show that an analysis like that done previously should also work for the 1990-2008 period. We omit some of the analysis done previously and concentrate on the days before expiration, days 1 through 42. Figure 28 shows plots quite similar to those of 21. Both panels show relationships between the adjacent periods 1-17 $\rightarrow$ 17-32 and 17-32 $\rightarrow$ 32-42, the p-values of the left and right panel regressions being, respectively, 0.08 and 0.05. Note that the ubiquitous significance level of 0.05 has no particular standing in these analyses; even relationships with much larger p-values can yield trading edges.

Figure 29 shows cumulative gains for contract 3 calculated as before, a trade in the intervals 17-32 or 32-42 is made at the beginning of the period in the same direction as the previous period, and exited at the end of the period. Clearly, gains in the interval 17-32 are better at predicting gains in 32-42 (right panel) than in the other case. On the x-axis of these plots is the expiration (there are 72 in all), and on the y-axis, the cumulative gain for the trading of one contract.

We will call the strategy of buying (selling) EFEED-3 Contract 3 on day 32 when the gain from days 17-32 is positive (negative), the *EFEED-3 Strategy 1*.

The total gain for the 19 year period of analysis is 623 Eurodollar ticks, for an average gain per year of 32.8 Eurodollar ticks. This is not an insubstantial gain! In fact, the target position from days 32 to 42 (two weeks) is held only 4

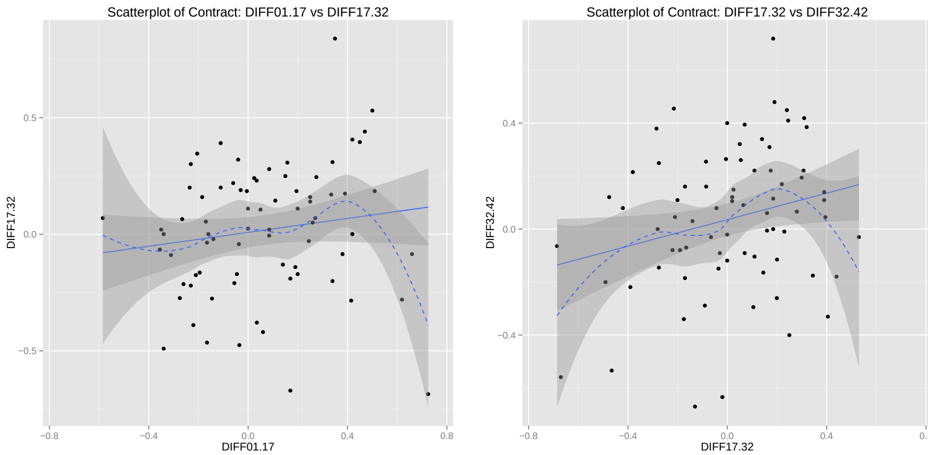

Figure 28: Trending relationships in the EFEED-3C period from day 1 to day 42 for the period 1990 to 2008.

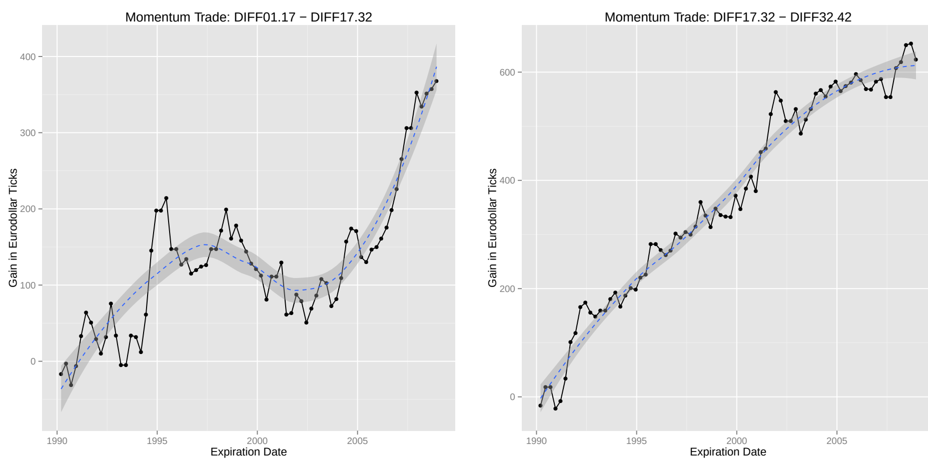

Figure 29: Cumulative gains for the 1-17 → 17-32 (left panel) 17-32 → 32-42 (right panel) trading strategies.

times per year, for a total of 8 weeks in 52 ($8/52 \sim 15\%$) and averages a gain of about \$820 per year on a one lot. The initial margin on a one year Eurodollar has varied over the years but probably has averaged about \$1,500 per contract. If, say, funds of \$5,812 per contract is required (see reasoning below), then the return per year would be about 14% per year before fees and slippage. Thus this preliminary estimate of system profitability is encouraging, but that does not make the system viable. For that we embark on a more detailed analysis, starting with the table below.

	np	npi	maxdd	pnlpp	ir	pnltot	sdpnl	winpct	runs	runspvu
Long	41	41	-65.00	10.96	0.45	449.52	24.38	65.85	21	0.70
Short	32	32	-112.47	5.44	0.19	173.98	28.07	53.12	14	0.19

```
All   76  76  -77.49  8.20  0.32 623.50 25.55  57.89   38    0.74
```

This table requires some explanation. The first row (*Long*) summarizes trades from the buy side, the second (*Short*) trades from the sell side and the third, all trades. The meaning of the columns is shown in Table 2.

Of the 76 quarters in the study of *EFEED-3 Strategy 1*, 41 were long and 32 short — a good balance considering the $\sim$ 7% upward bias in Eurodollar prices over the study period. The reason that the *np*'s for Long (41) and Short (32) don't sum to 76 is that there were three quarterly expirations (1993-06-11, 1995-12-15, and 2007-09-05) for which the gain on days 17-32 was 0, and therefore did not generate trades. But those 0 gains are included in the *All* line summary. Recall that the system averages 32.8 ticks per year, so a drawdown of $maxdd = -77.49$ is quite high, the average recovery being 77.49/32.8) = 2.36 years. The *maxdd*'s for the *Long* and *Short* don't make sense for the entire system, but they would apply if a *Long-only* or *Short-only* strategy were to be used. The winning percentage of 57.89 is outstanding. Here is a grational rule of thumb we use to determine a system's viability: assume that the worst drawdown of the system should not lose more than 33% of funds, we call that the *3xDD rule* for short. This rule should be used only to determine system returns if traded alone and a 33% drawdown is acceptable. Similar rules can obviously be used, e.g. the *5xDD rule* for 20% drawdowns. With this rule, one should allocate trading funds of $3 * 77.5 * \$25 = \$5812.5$ per contract resulting in a return of 14% per year (or 21% for 2xDD, 10.5% for 4xDD, and 8.5% for 5xDD).

Referring to Figure 29, there are three periods with large one-way gains; the first in the period from Q4 1990 to Q2 1992, the second in 2001, and the third in 2007. Further, the graph shows a tailing off in at the right boundary. Later we shall describe important events that occurred in conjunction with these moves.

Table 2: Column descriptions for trading system profit & loss summary.

Column Name	**Description**
np	The total number of periods.
npi	The number of periods "in the market," that had a position.
maxdd	Maximum peak-to-trough drawdown.
pnlpp	P&L per period (%).
ir	Information ratio = (mean ret)/(sd ret).
pnltot	Total of trade returns for the entire period (not compounded).
sdpnl	Standard deviation of P&L per period.
winpct	Winning percentage.
runs	Number of runs.
runspvu	P-value for too few runs.

7 Analysis of Eurodollar Expirations

7.1 Analysis of the Eurodollar EFEED-3 Dataset

The knowledge that the FED often telegraphs its intentions suggests that there might be a system that bets across quarters, not just within quarters.We begin with the event dataset EFEED-3 (the price dataset) described in the paragraph "How to Extract Principal Component Factors" of Section 6.3.2 and perform a principal component analysis. Figure 30 shows a variance histogram for an analysis of Contract 3 of this dataset. Obviously, almost all the variance is in the first principal component, because the level of Eurodollar Futures prices dominates any 63-day shape components.

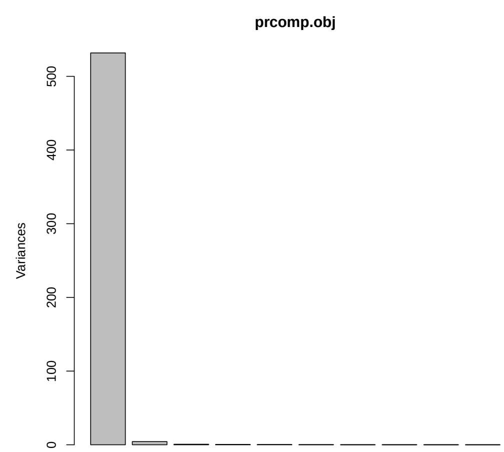

Figure 30: Eigenvalue plot for PCA EFEED-3, Contract 3.

Figure 31 has signals (left panel) and profiles plots for the first four components of the PCA analysis. The first component in the northwest corner of each panel is the dominant component. Consider the profile first. Although the profile seems irregular, the range of coefficients is small, from 0.0124 to 0.128; the positive slope in the middle portion is consistent with the upward drift of the EFEED-3S analysis (Figure 20). But the signal itself is quite interesting, and quite promising. The reason is that the trajectory of the signal is quite regular, so it is possible that a trend following system can be deployed to follow that trend.

An enlarged copy of this signal is shown in Figure 32. A simple method can be used to trade with this signal: (1) calculate the signal for a 63 day period, (2) add it to a list of those already calculated, then compute its difference from the previous one, (3) buy on EFEED day 1 of the period if the difference is positive, sell if negative. We call this strategy the *EFEED-3 Strategy 2*.

This is obviously a crude method, and certainly amenable to improvement. But as we'll see below, it is adequate nonetheless.

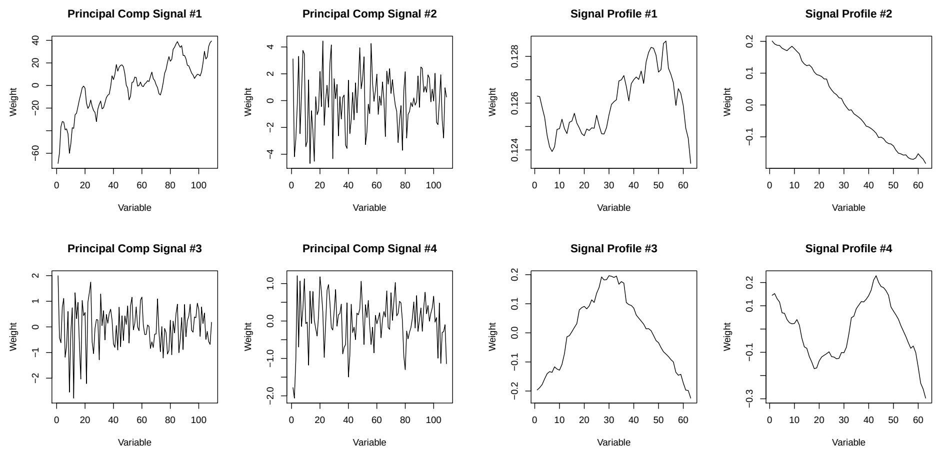

Figure 31: PCA for Signal (left panel) and Signal profile (right panel) for Contract 3 of dataset EFEED-3.

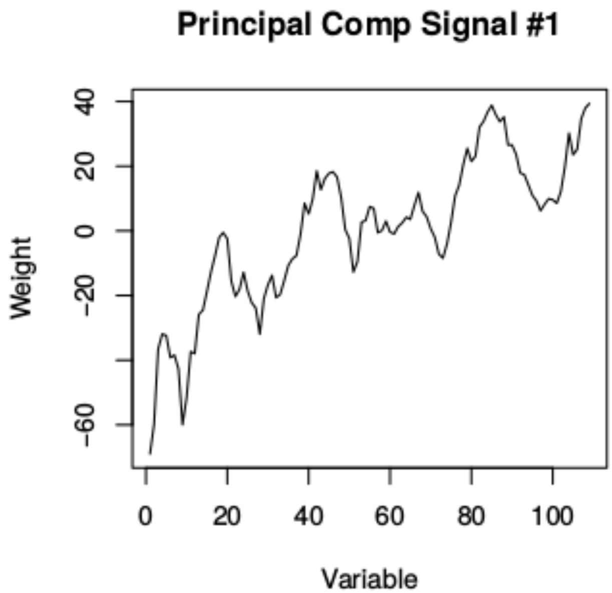

Figure 32: Dominant signal of PCA on Contract 3 of dataset EFEED-3.

Prior to developing this system, we produce a fair benchmark by rolling contract 3 of EFEED-3 on day 63. This is comparable to a long-only buy and hold in stocks; we refer to it as the *Eurodollar Day 42 Roll Strategy*, or just the *Roll Strategy* for short. The cumulative P&L curve for the roll strategy is shown in Figure 33. The only difference between the *Roll Strategy* strategy and *EFEED-3 Strategy 2* is that the latter is sometimes short when the other is long.

7.2 Returns from Quarterly Rolls

We construct the *Eurodollar Roll Strategy* as follows. Buy Eurodollar Contract 4 41 days prior to expiration and simultaneously sell the previous contract. Hold Contract 4 (which becomes Eurodollar Contract 3 after expiration) which will generally be either 21 or 28 days after expiration. This procedure of selling the 3 Contract and buying the 4 Contract is called a *roll*. Ignoring the cost of the roll, what should the returns from such a strategy look like. Figure 33 shows the gains expressed in Eurodollar ticks over the 108 expirations in the *EFEED* dataset.

Figure 33 shows the gains of this strategy from 1990 until the end of 2008. The total gains over that period are XXX, which as explained earlier, is due entirely to the increase in Eurodollar of approximately YYY.

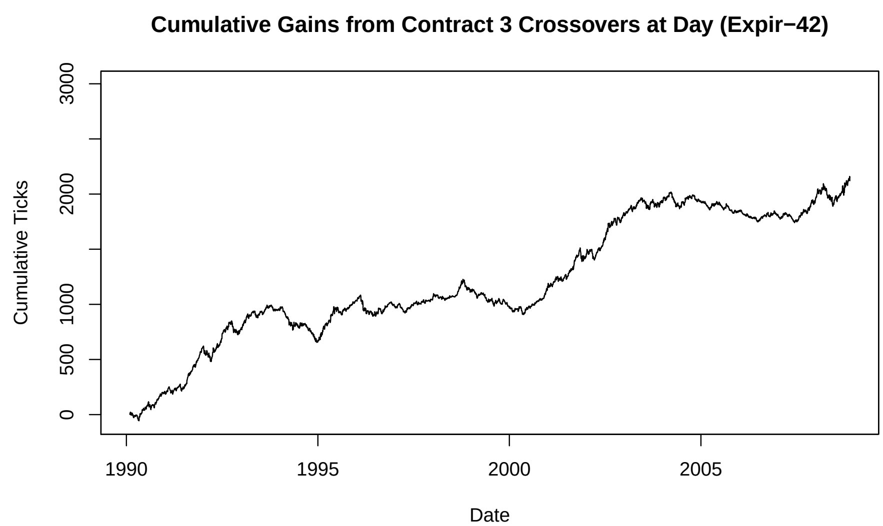

Figure 33: Cumulative Returns from the Roll Strategy (Quarterly Crossover of Six Month Eurodollar Futures Contracts).

7.3 Analysis of the EFEED-3 Strategy 2 and the Eurodollar Roll Strategy

Figure 33 compares cumulative gains of the *EFEED-3 Strategy 2*(higher line) and *Eurodollar Roll Strategy*. Visually, a couple of things are clear: (1) *Strategy 2* earns about 837 ticks more (2115 vs 2952), or about 39% more than the *Roll Strategy*, and (2) its appears to have smaller drawdowns. But these are just visual impressions; for a better analysis we perform a profit & loss analysis next.

	np	npi	maxdd	pnlpp	ir	pnltot	sdpnl	winpct	runs	runspvu
Sys2 Long	2410	2410	-138.49	1.05	0.12	2533.54	8.50	56.72	1097	
Sys2 Short	1894	1894	-232.51	0.22	0.03	418.37	7.83	52.48	932	
Sys2 All	4730	4304	-205.50	0.69	0.08	2951.91	8.22	54.86	2026	0

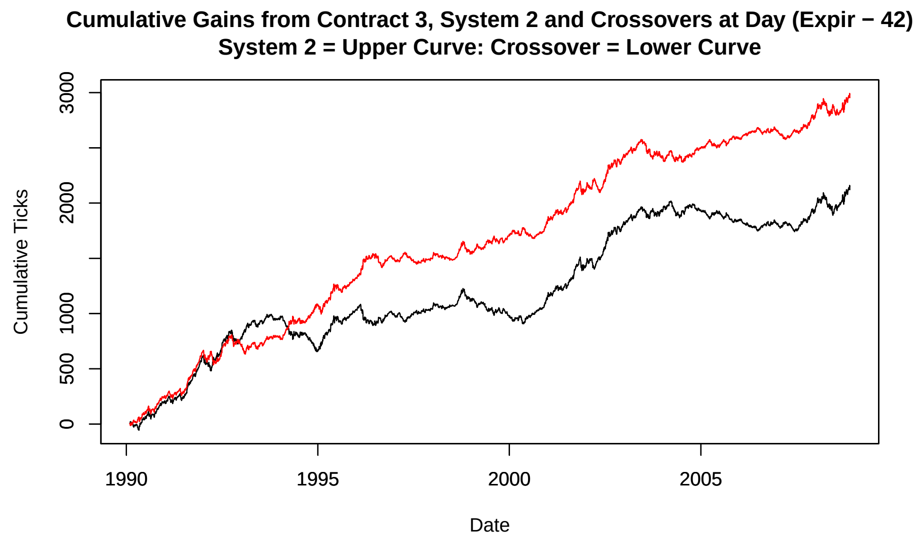

Figure 34: Cumulative Returns from replace with the Roll Strategy (lower line) vs. *System 2* (upper line).

	np	npi	maxdd	pnlpp	ir	pnltot	sdpnl	winpct	runs	runspvu
Roll	4730	4304	-338.00	0.49	0.06	2115.17	8.23	52.67	2029	0

The table above has summary statistics for the *EFEED-3 Strategy 2* and *Eurodollar Roll Strategy*. Definitions of the columns are contained in Table 2. For the moment, ignore the *Sys2 Long* and *Short* lines and compare the *Sys2 All* and *Roll* lines. First, note that the total gain gain of *Sys2* is about 837 ticks higher than the *Roll*, or an improvement of about 39%. Since the only difference between these systems is periods that the *Sys2 All* goes short, we conclude that the short side trades must net about $837/2 \sim 418$ total ticks over the test period. Second, note the considerable drawdown reduction: -205 for *Sys2* and -338 for *Roll*. The column *pnlpp = ticks/period* shows that the gain per day is about 0.20 ticks higher in *Sys2* than *Roll*. As expected, the winning percentage is over 2% greater in *Sys2* (54.86 vs. 52.67. The final two columns for 'Sys2 All', *runs* and *runspvu*, show the number of runs (about 2026) in a series that had 4304 periods in the market which is very high. The column shows the one-sided p-value for a test (*runspvu*) against too many runs. The p-value of of 0 to 6 decimal places indicates that the trading system gains are much choppier than one would expect at random.

Consider now the *Sys2 Long* and *Sys2 Short* lines. The most striking thing is the lopsided gains in favor of the long side, 2533.54 vs. 418.37 and one might be tempted to drop the short trades. However, this is generally a mistake. The main tactical reason in this case is that there has been a VERY favorable environment for the long side during the test period, and if that environment now changes, short side trades could perform equal to or better than long side trades. Consider the ir lines and note that the $0.12 - 2 * 0.03 = 0.06$ is the ir for the *Roll* strategy. This works only because the standard deviations of all systems are quite similar (range 7.83 to 8.50).

Returns for a 3xDD system can be calculated from the 76 quarters of *System 2*. With a maximum drawdown of 205.5 ticks, and a yearly return of 2951.91 ticks, the annual return is

$$(2951.91/19)/(205.5 * 3) \sim 25\%.$$

This return seems high, given that Eurodollar rates never came close to 25%. Note the illusion here: the denominator of our calculation is three times the maximum historical drawdown since 1990, and that drawdown is partly due to the reduction in volatility from *System 2*. What this indicates is that *System 2* is not very volatile for the return it generates. For more conservative choices of 4xDD and 5xDD, the returns are 19% and 15%, respectively, still excellent for a "safe" credit instrument.

8 Future Performances of Systems 1 and 2

The last step of the *The Strategic Analysis of Markets Method (SAMM)* (see page 3) advises identifying the POPP phases of the two strategies' life cycles. Briefly, both strategies at the end of 2008 appear to be in Phase (B), the *Early Copycat* phase. I'm not going to justify this belief, but may write further in the future on methods for identifying POPP phases.

The greatest threat to Systems 1 and 2 returns is lowering of rates along the curve, which in fact, happened after 2008. But this system was developed in 2015 with the purpose of investigating the use of the *SAMM* and I recognized at the time that returns were reduced in the low rate environment of 2009 to 2015. I considered modifying the systems to use 2-year Eurodollar futures (because of increased activity further out on the curve and higher rates there) but have not done so. In any case, rates for 2-year Eurodollars are still extremely low compared to the historical period. I would expect that these Systems still work circa 2018, but return much less than they did from 1990-2008.

The other important question, though, is whether the disclosure of these strategies might lead their getting arbbed out. As background, we observe that the Eurodollar market consists of U.S. Dollar deposits in foreign banks and all associated derivative products, such as OTC forward rate agreements, Eurodollar futures, Eurodollar options, swaps on Eurodollars and so on. Moreover, many other credit markets are indexed to Eurodollar rates. Eurodollars and associated markets are deep, deep international markets of which Eurodollar futures are one small part that competes with OTC markets for interest rate hedging. If there were increased System 1 or 2 activity, it does not seem plausible that it would be large enough to materially affect these other Eurodollar markets — and I believe that the dog wags the tail, not conversely. For hedgers sensitive to Eurodollar pricing, the main risk is reduction in hedging effectiveness. Should strategy disclosure lead to changes in the timing of the roll, one should expect System 1 to be more vulnerable than System 2. Reduced returns in System 2 due to a shift in timing of the roll, should be a warning for System 2. Because of the large number of players that are likely inflexible in their roll timing, any shift of the kind suggested here would probably occur slowly.

9 Summary

It is worth reviewing the results of this article in order to place them in a wider context. We began with a superficial description of Eurodollar markets and a more detailed description of Eurodollar futures markets. We then discussed the difficulties of creating a spliced-together series from futures. A constant maturity contract was constructed and an ICA analysis showed a remarkable "zig-zag" pattern. But it was demonstrated that those "constant maturity returns" were not achievable in practice, and the pattern disappeared when conducted on real prices. Generalizing, it is generally inadvisable to use constant maturity prices for trading system development.[7]

These analyses were typical of curve-fitting approaches, but were insufficiently motivated from the viewpoint of strategic analysis. Therefore, an analysis of why and how U.S. credit markets might be beaten was undertaken. Four sources for *Potentially Profitable Gambling System (PPGS)* were identified:

1. The Federal Reserve System and the Spirit of the Times.
2. Segmentation that Causes Yield Curve Patterns.
3. Event Plays.
4. Inefficient Forward Markets.

We chose to investigate Eurodollar Futures market rolls, since that is an *event play* in a putatively *inefficient forward-like market*.

Several variations of an event dataset/format were developed, in each case to ferret out non-random, predictable patterns around Eurollar expirations. One reason for that predictability around expirations is that Eurodollar players often roll positions forward near expiration. Much Eurodollar volume is just spill-over from banks and other intermediaries hedging their forward market positions, and so one expects a considerable roll volume to occur.[8] And from the standpoint of strategic traders, the nice thing about hedger/arbitrageurs is that they're willing to give up edge for safety.

Large hedgers in any market are a source of potential trends. Why? Because their positions are too large to liquidate immediately, so they have to liquidate slowly. This might be an effect in, for example, stocks that have negative SUE's. A fund with lots of shares won't be able to get out immediately but will gradually sell shares exerting negative price pressure on the stock. But does this effect exist in Eurodollar futures? Uncertain, but I doubt it.

Based on these considerations, several guidelines for an analysis were identified:

[7] The St. Louis FRED data repository (FRED II) supplies constant maturity prices for the U.S. yield curve. Read the fine print of your data sources!

[8] But the Eurodollar futures action is just a tiny part of the interbank market.

1. Look for pattern heterogeneity.
2. Ignore averages.
3. Look for subpatterns that don't span the entire 63 days.
4. Emphasize search within a few days of the expiration.
5. Unusual moves in a contract may have ripple effects.
6. In Eurodollar futures analysis, spread price changes may indicate market maker distress.

Based on these principles, an EFEED-3S dataset of "expiration shapes" was described, and a principal components analysis run on it. The signal profiles showed interesting patterns, especially in their turning points. In Section 6.2, the prominent turning points occurred around days 17, 32 and 42 of the expiration cycle, with day 42 as expiration day. Then the 63 day cycle was partitioned into 5 intervals and scattergrams of any gains predictability (using linear regression and loess) were produced. Two candidates emerged: the gains on days 1-17 mildly predicted those of 17-32, and the gains of 17-32 mildly predicted those of 32-42. Upon testing using gains in prices (not shapes), the pair 17-32 $\rightarrow$ 32-42 seemed superior. The simple trend following system that retained the same sign as the previous period yielded the *EFEED-3 Strategy 1* that despite trading only about 15% of the days in each year, returns about 14% per year with a *3xDD rule*.

The known persistence of FED rate policy makes an inter-expiration system possible. In this case, the mechanism is the "FED" gives away money" scenario due to their pursuing a (partly) predictable strategy, or what Chapter 9 of Moffitt (2017a) called a *partial disclosure* action. Using a PCA analysis on the Contract 3 EFEED-3 dataset of prices, with a momentum rule based on the previous expiration gain, another system, the *EFEED-3 Strategy 2* was developed. Using the 3xDD rule, it returns about 25% per year, and greatly outperforms the baseline *Eurodollar Roll Strategy*.

These results are impressive, but are these system viable? Short answer: Yes for *EFEED-3 Strategy 2*, perhaps not for *EFEED-3 Strategy 1*. The cost for Strategy 1 is about 8.5% per year, but the cost for *EFEED-3 Strategy 2* is only 3-4% per year.

Some brief remarks about leverage are in order. Leverage was approached using a modified principle of grationality — choose your bankroll to lose an acceptable amount on a severe drawdown. The *nxDD* rules, 2xDD, 3xDD, etc. are intended as screening rules only to determine strategy viability. If one trades the single system being tested and that's all, then a conservative rule like the 5xDD or 6xDD rule is advisable. But it is more common for several strategies to be traded as a portfolio, and in that case even a 1xDD strategy can be viable. The reason is that strategies generally partially offset each other, one winning while others lose. which "self-finances" the increased leverage.

In closing, we state the obvious fact that these two strategies were not optimized, and that there are methods to improve returns above and beyond those demonstrated. We leave these as an "exercise to the reader." But the basic principle of viewing markets as a game in which strategy disclosure can lead not just to potentially profitable gambling systems, but to *actually profitable gambling systems* is the point of this article. That these two systems are so easily discovered in a deep market that ought to be among the most efficient, reinforces that the theory of efficient markets is folly.

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Glossary

9/11 An abbreviation for the date of the World Trade Center attacks of September 11, 2001. Apart from its political and historical significance, 9/11 had a significant impact on the U.S. economy. 11, 14, 15, 28

algorithmic trade (1) In a PPGS renewal process, all the transactions occuring from the time of the founding transaction until that transaction is closed, and (2) the part of a mechanical trading system, usually computer-assisted, that performs computations to buy or sell. 3, 55

arb Nickname for an arbitrageur. 8, 27

arbbed out Referring to a mispricing that has been corrected through arbitrage. 33, 50

arbitrage A strategy that buys and sells the same or statistically similar securities at advantageously different prices, e.g. index arbitrage, pairs trading, options delta-neutral hedging. See also pure arbitrage and statistical arbitrage. 7, 8, 23, 27, 28, 33, 34, 55, 58

arbitrageur A trader whose dominant strategies are arbitrages. 11, 51, 55

back end A term used for the longer maturity instruments of the yield curve, typically ones with a maturity of 5 years or more. 16, 27

backtesting The process of applying quantative methods to a trading system's historical or simulated performance to determine if it is worth trading. 6

behavioral finance The study of finance which examines how market phenomena arise from the interactions of its human participants. BF has untrustworthy roots in anthropology, psychology, social psychology and sociology. 3

carry trade A strategy that finances an pspeculative by trades borrowing in a currency that has relatively low interest rates. 58

closing transaction In a PPGS renewal process, a transaction that exits an algorithmic trade resulting in no residual position. 21, 59

CME Chicago Mercantile Exchange. 8–10

direction In mathematics, a vector having unit length. 14, 58

discretionary trade A trade initiated by a human trader using judgment, not a purely mechanical algorithm. 3

distortion factor Any exogenous news, constraints on trading, widely held beliefs, or widely used strategies that effect price impacts. For example, the fact that mutual funds cannot short stocks suggests that prices might be higher than they would be if shorting were allowed. Same as price distorter. 57

Dot-com Bubble A remarkable modern bubble (1996-2000) powered by the fantasy of a "new economy." The story line was that ".com" (read: "dot com") companies would in time eradicate conventional retail storefronts by offering products online. In a scant four years, this craze caused the Nasdaq composite index to quadruple, going from about $1,200$ to over $5,000$. But remarkably, an abrupt crash did not occur; instead, there occurred a slow, steady and punishing decline back to about $1,500$. 27

drawdown If not explicitly stated otherwise, a peak-to-trough drawdown of a financial time series is its greatest loss from a previous high usually expressed as a percentage. For example, a series that had a previous high of 1000 and a lowest low later of 800 would have at least a 20% peak-to-trough drawdown. 7, 21, 45, 52, 56

edge A gambling term for the expected gain or loss from a bet. A bet with positve expectation has "edge", and one that is not positive, has no "edge". 6, 10, 43

FED Federal Reserve System. 11, 15, 24, 25, 28, 51, 52

founding transaction In a PPGS renewal process, a transaction that initiates a position, i.e. when the prior position is zero. 21, 55, 59

front end A term used for the shorter maturity instruments of the yield curve, typically ones with a maturity of less than 5 years. 16, 27

game theory The study of rules-based, possibly stochastic, contests in which two or more participants (players) make decisions according to the rules, and receive payoffs as a function of a terminal outcome. A *solution* in game theory consists of strategies for the players that are in some sense optimal. 57, 59

George Soros Arguably the most successful, but unquestionably the most famous hedge fund manager of the latter 20^{th} and early 21^{st} centuries. 27

girrational Said of an investor who is not grational. 56

Global Financial Crisis The financial conflagration that was clearly discernible by 2007 when the subprime mortgage market melted down, by the fall of 2008 becoming a worldwide crisis of all financial markets, finally ending in the spring of 2009. The worst crisis since 1929. 16, 25–27

grational Said of an investor whose criterion for trades is that they have expected return of at least r and probability of drawdowns exceeding d no more that p. See also girrational. 6, 21, 45, 52, 56

Great Depression The worldwide financial collapse that followed the stock market crash of 1929, and lasted for nearly a decade. 25, 57

high-frequency Data having short, usually irregular, time spans between successive observations. In this work, it refers to data occurring, or sampled at, time periods less than or equal to 15 minutes. 25

ICA independent components analysis. 15–18, 20–22, 37, 51

independent components analysis A method of decomposing a multivariate dataset into components that are maximally independent. There are several different methods of calculating such components, depending on the measure of independence used. 14, 15

information set For a time series $\{X_t\}$ at time t', a set $I_{t'}$ that gives data known at t'. Generally used to form a conditional distribution $X_{t'+1} \,|\, I_{t'}$ for the next-period value, $X_{t'+1}$. 20

insider trading The deplorable practice of trading on non-public information in advance of its market moving impact. At this writing, insider trading is illegal in the United States, but not in Monaco. 5

k-nearest neighbors A smoothing method for a scatterplot $x_i, y_i)$, $i = 1, 2, \ldots, N$ which for a given x_0 finds the k nearest x_i, and averages the y_i associated with them. See also loess. 56

leverage Refers to the common financial practice of purchasing or shorting financial instruments by pledging only a fraction of their nominal value. The difference of the cost of the purchase or short is generally supplied at interest from a bank or institution that specializes in lending to trading entities. 9, 22, 28, 33, 34, 52

loess A smoothing method for a scatterplot $x_i, y_i)$, $i = 1, 2, \ldots, N$ which for a given x_0 finds the k nearest x_i (where $k = \alpha N$), and averages the y_i associated with them. See also k-nearest neighbors. 39, 52, 56

lookahead bias In trading system development, the (often inadvertent) development and testing of a trading system using information assumed to be known at trade time, but in actuality known only at some future time. Some real life examples: (1) using a sentiment index dated on Friday of each week, but not made available until the following Tuesday, and (2) simulating a trade in the middle of a period based on the mean price of the entire period, but then in practice using the mean available from the beginning of the period to the trade time. 36, 39

mechanical trading system In trading and investment, a collection of well-defined rules that specify when to enter the market, the size and side (buy or sell) for entry, and when to exit all or part of an existing position. In this work, the same as a trading system. 7, 55, 59

NASDAQ National Association of Security Dealers Exchange. 4

New Deal The slogan adopted by U.S. President Franklin Roosevelt for his progressive program during the Great Depression. In financial markets, the New Deal involved regulation of the financial system to punish undue speculation and afford a measure of protection to average investors. 25

overreaction In financial markets, overreaction refers to an excessively large price move in response to an event. See also underreaction. 28, 59

pairs trading strategy A *pairs trading strategy (PTS)* is any strategy that selects from some universe of stocks those price-pairs that have a putatively overvalued and undervalued member, and nearly simultaneously buy the undervalued and sell the overvalued. The pair so-formed is then liquidated when prices are judged to return to "equilibrium.". 55, 58

partial disclosure A non-standard term in game theory in which a player discloses that he or she will pursue a certain strategy with some probability p, $0 < p < 1$ and $p \neq 0.5$. 52

PCA principal components analysis. 20–23, 34–38, 41, 43, 46, 47, 52, 58

potentially profitable gambling system A potentially profitable gambling system (PPGS) is a betting system for a financial time series $\{X_t\}$ that produces net positive expected returns before deducting expected slippage and costs of trading. 3, 4, 51, 53

PPGS Potentially Profitable Gambling System. 28, 39, 40

PPGS renewal process A potentially profitable gambling system renewal process is an algorithm that (1) produces transactions depending on the state of the market and its own trading history, (2) as a function of those inputs, produces trades each consisting of a founding transaction that initiates a position from a state having no position, a closing transaction that liquidates remaining positions leaving a zero position, and has no other transactions between founding and closing that change the founding position from long to short or short to long, and (3) produces a potentially unending stream of trades (renewal). 55, 56

price distorter Any exogenous news, constraints on trading, widely held beliefs, or widely used strategies that effect price impacts. For example, the fact that mutual funds cannot short stocks suggests that prices might be higher than they would be if shorting were allowed. Same as distortion factor. 3, 5, 6, 55

price impact The change in price due to a trade or sequence of trades, as a function of price, quantity and market depth. Note that concept is ill-defined, in the sense that it assumes a counterfactual price that would have obtained in the absence of that trade or trade sequence. Since markets are replete with "nuisance variables" that are demonstrably important in determining price impact, in practice one usually settles for estimates of average impact using statistical models. 3, 5, 55, 57

principal components analysis A method of decomposing a n-multivariate dataset into $m < n$ mutually orthogonal directions such that the sum of the variances associated with the directions is maximal over all other sets of m directions. PCA results from performing an eigenvalue decomposition of the covariance matrix and selecting eigenvectors associated with the m largest eigenvalues. 14, 15, 34, 38, 52

profile In the technical trading terminology ot this book, a *profile* or signal profile is a collection of vectors $v_t \in \mathbb{R}^n$, that at each time t gives a trading signal for trading variables $p_t \in \mathbb{R}^n$ as a scalar product $v_t \cdot p_t$. If $v_t = v$ is constant for all t, then the *profile* is called *stationary.* For the most part, methods used in this book produce stationary profiles. 15, 18, 46, 58

profit & loss and abbreviation for *profit and loss*. 9, 19–21, 45, 48

pure arbitrage An arbitrage having such small risk that a profit is almost certain, e.g. the near simultaneous purchase and sale of the same security on two different exchanges at advantageously different prices. 55

Pursuit of Profits Paradigm A type of strategic evolution in which a “chase after riches” leads to boom-bust cycles in markets. 3, 4

riding-the-yield-curve A type of carry trade in which short maturity notes are sold and long maturity ones purchased, and as short maturity ones mature are replaced by new ones. When the yield curve is upward sloping, the trade has positive returns; when it inverts, though, the trade loses. 28

S&P 500 Standard & Poors 500 Index. 4

SAMM Strategic Analysis of Markets Method. 58

signal In the terminology used in this work, a *signal* at time t is a statistic calculated from data available on, or prior to t, for use in making trading decisions. 15–18, 20–23, 36, 37, 46, 47

signal profile In the technical trading terminology ot this book, a *signal.profile* or just profile is a collection of vectors $v_t \in \mathbb{R}^n$, that at each time t gives a trading signal for trading variables $p_t \in \mathbb{R}^n$ as a scalar product $v_t \cdot p_t$. If $v_t = v$ is constant for all t, then the *profile* is called *stationary.* For the most part, methods used in this book produce stationary profiles. 15–17, 22, 23, 37, 38, 41, 47, 52, 58

slippage In the context of trade execution, the difference between the target price of a trade and the actual price of execution. For example, a purchase of $1,000$ shares at target price price \$10.50 might be executed instead at \$10.60, in which case the slippage is \$0.10. In general, the slippage will be greater the larger the trade, and this must be accounted for in the backtesting of any trading system. 18, 19, 44

statistical arbitrage An non-pure arbitrage having a positive expected return, e.g. index arbitrage, pairs trading, options delta-neutral hedging. 55

Strategic Analysis of Markets Method The *SAMM* is a framework for developing trading systems by using game theoretic, strategic and statistical analysis. As such, the SAMM is one degree removed from flesh-and-blood humans, but in its favor, is amenable to game theoretic analysis. 3–5, 7, 23, 50

strategic evolution A process in which strategies change, often in a patterned way, over time. The Minsky-Kindleberger Model is one example of strategic evolution. 58

strategic plan An incomplete trading scheme or idea that has parameters which if specified convert it to a trading algorithm. A plan such as “Buy in a bull market, sell in a bear market by ,” is not a strategic plan as it stands, but could be one if parameters type={bull, bear, neither}, asset={set of tradable assets}, execution={open,close}, and any other variables that are required to decide what and when to buy and sell, are added to its statement. 3–5

strategy (a) In game theory, a complete specification of the choices that a player would make under every possible game contingency, (b) In trading, a set of guidelines, a set of rules or an algorithm that a trader, investor or computer uses to buy and sell. Some strategies are purely mechanical and can be executed by a computer. Some are purely discretionary, and require one to treat human decisions to buy and sell as an algorithm, albeit one that cannot be programmed. 3

SUE An acronym for *Standardized Unexpected Earnings*, defined as the current earnings minus those of a year ago (YoY earnings) divided by their standard deviation. 5, 28, 51

tick A unit of change in a futures contract. In Eurodollars priced to two decimal places, a tick is a change of 0.01, e.g. 94.32 to 94.33. Generally, a tick is a minimum change, but that rule has many exceptions. Some Eurodollars, for example, are prices in *half-ticks* (0.005) or *quarter-ticks* (0.0025). 9, 11

trade In this work, a founding transaction followed (eventually) by a closing transaction that exits the entire position created by the founding and any subsequent transactions that maintain a position on the same side of the market. This concept deviates slightly from trader's parlance, in that there may be many reductions in the size of the opening transaction before its complete closing. When refering to historical closed trades, is called a *closed trade*, while when ongoing (not yet closed), is called an *open trade*. 55

trading algorithm In trading and investment, a collection of rules for trading that are specific enough to be implemented as a computer program, requiring no human intervention beyond decisions of when to use them. 3, 4, 6, 7, 58

trading system In mechanical trading and investment, a collection of well-defined rules that specify when to enter the market, the size and side (buy or sell) for entry, and when to exit all or part of an existing position. In this work, the same as a mechanical trading system. 57

transaction A transaction is an executed or partially executed order, that is, one in which a quantity of a financial instrument bought or sold at a particular time and place. 7, 18, 20, 21, 25, 55, 56, 59

trend follower A trader that follows trends, that is, who buys when price is going up and/or sells when price is going down. 46, 52

turnover ratio For stocks, the ratio of the quantity traded over a specified period to the shares outstanding. For example, the daily turnover ratio of stock XYZ is the daily volume of XYZ divided by its shares outstanding. 4

underreaction In financial markets, underreaction refers to an insufficient price move in response to an event. See also overreaction. 5, 28, 57

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