High Frequency Pairs Trading with U.S. Treasury Securities: Risks and Rewards for Hedge Funds

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Abstract

This paper examines the implementation of a simple pairs trading strategy with automatic extreme risk control using the entire universe of securities in the highly liquid secondary market for U.S. government debt. It documents, from a practical viewpoint, the contrasts in the generic features of pairs trading with such securities compared with equities. The rewards emanating from the proposed strategy, after constructing an appropriate risk benchmark, are appraised using various traditional and relatively newer metrics. Using data from the repo and money market, estimates are also made of the distribution of absolute returns after accounting for financing and transaction costs.

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1. Introduction

Non-traditional money managers have employed the concept of pairs trading for many years. Hedge funds and proprietary trading desks of investment banks used this simple statistical arbitrage strategy with an apparent degree of success. As a strategy, it is very easy to conceptualise. Find two securities that have moved together in price space. Monitor the spread between them. When the spread widens, buy the loser and short the winner. If the two securities have a stable relationship, the spread will narrow to its normal historical levels. At that time, reverse the trade and pocket the profit.

The practical implementation of terms such as “find two securities”, “monitor the spread”, “stable relationship”, “normal historical”, “reverse the trade” and “pocket the profit” are what make such a strategy more challenging in reality than it is in theory. Besides these, market incompleteness such as ex-dividend date jumps, and market frictions such as transaction costs, financing costs, taxes and immediacy make the task less easy and the rewards usually lower. Also, this so-called “arbitrage” is not riskless. In practice, even in the absence of the frictions mentioned above, the arbitrage is rarely ever a “pure arbitrage”, but is what is often called an “expectations arbitrage”. There is always some risk inherent in the strategy. This risk could be attributed to a number of areas. It might take, for instance, a microstructure nature e.g. inability to find a counterparty for an immediate sale. Or, it might be based on pure economic fundamentals e.g. a change in investors’ interest rate expectations represented by a change to the curvature of the yield curve. It could be institutional in nature e.g. a sudden demand and ultimatum for margin payment. Or, it could be noise trader risk where the fundamental economic values of the two securities, based on ultimate payoffs, are exactly the same, but the aggregate of informed and uninformed investors trades them at even more disparate prices than when the spread trade was opened. Usually, the pairs trader faces more than one of such risks simultaneously.

In the academic literature on the U.S. Treasury securities market, Krishnamurthy (2000) examines the classic trade involving a short position in a newly issued 30-year Treasury bond and a long position in the old 30-year Treasury bond. He estimates that the profits from this strategy are greatly reduced once the cost of financing in the repo markets is taken into account.

Gatev *et al* (1999) examine pairs trading in the U.S. equity market. They confirm that this popular Wall Street investment strategy is profitable after an allowance for trading costs, and that these profits are inherently different from a pure mean-reversion strategy. Unfortunately they do not address the difficulties or costs of shorting in that market.

This chapter examines a simple pairs trading strategy using the large and highly liquid secondary market for U.S. Treasury securities.[1] There does not

[1] Bradley and Lumpkin (1992) show that the US Treasury interest rates are strongly cointegrated.

exist any prior academic research that has used the entire universe of U.S. Treasury bills, notes and bonds in a single study. Although this chapter may appear to make implicit statements about the level of efficiency in this market, this is not one of its aims at the outset. Instead, it examines the risk reward tradeoffs of pairs trading in the secondary market for U.S. Treasury securities. It estimates the returns distribution from following such a strategy after accounting for transaction and financing costs. A duration-matched portfolio is constructed to benchmark vis-à-vis the primary component of net risk in the fixed income portfolio. The returns of various strategies, benchmarks and market indices are then put through a relative appraisal, using metrics such as the *gain-loss ratio* (Bernardo and Ledoit (2000)) and *omega measure* (Keating and Shadwick (2002))

Section 2 describes some of the practical issues for setting up a pairs trading strategy. It contrasts equities and government bonds in this respect. Section 3 describes the data used. Section 4 discusses the main features of the proposed pairs trading strategy, including the simple risk management strategy suggested. Section 5 contains the analysis and main results. Section 6 concludes.

2. Practical Issues when Pairs Trading

Table 1 lists some of the main features to be considered when implementing pairs trading. It also shows how each feature differs when pairs trading with U.S. equities rather than U.S. Treasury securities. For a trader with limited capital who wishes to trade a pair in the U.S. Treasury securities market, she must be able to carry out a series of operations with different intermediaries (each charging a fee) for the opening leg of the spread trade. This is shown graphically in Figure 1. The mechanism is opposite when reversing the trade in the closing leg.

In its most generic sense, the pairs trader will:

- look over some (recent) historical "training period"
- at some subset of the universe of available securities
- to decide how to form pairs, which she will then
- trade over some future "trading period"

Thus, the decision variables to consider are:

- the length of the "training period"
- the subset of securities, within an asset class, to choose from
- the metric for measuring which is the best partner for a security
- the cut-off for the metric when deciding which pairs are too unstable to even bother with
- the length of the "trading period"
- the trigger point at which a spread trade is opened
- the trigger point at which a spread trade is closed
- steps for risk control

In practice, she will also have to consider:

- her relationships with dealers and brokers in both the cash and repo markets
- ways to reduce commission payments through such relationships
- methods to raise debt capital at a short notice
- lines of credit for financing margin payments that are in excess of any equity capital that she starts with
- the behaviour of the owners of equity capital when her P&L is under duress

3. Data

3.1 Cash Market

The secondary market in U.S. Treasury securities is predominantly an over-the-counter market. Although Treasury securities are also listed on the New York Stock Exchange (NYSE), trading volume on the NYSE is negligible in comparison with the over-the-counter market.

The over-the-counter market consists of approximately 1700 brokers and dealers. Brokers are solely intermediaries that bring dealers and customers together for a small brokerage fee whereas dealers take the opposite side of a customer transaction. For providing this service to investors dealers earn the bid-ask spread. In order to supplement their revenue from market making, most dealers also engage in proprietary trading.

In addition to regular brokers, there are six interdealer brokers who provide their services to dealers only. Inter-dealer brokers conceal the identities of the ultimate sellers and buyers, and act as principals to both sides of the trade. Thus, there are two ways for a dealer to make a quotation or trade with another dealer - via direct connection with the other dealer or via a screen of an interdealer broker.

In spite of the large number of dealers in the over-the-counter market, the vast majority of the quoting and trading activity is by the 35 primary dealers. Primary dealers differ from other dealers in that they are approved to transact directly with the Federal Reserve in its market operations. Primary dealers are expected to participate in Treasury auctions and distribute Treasury securities as well as make a market for customers.

The data set on the U.S. Treasury market that is used in this study is from GovPX. GovPX is an organisation that was set up in 1990 by all the primary dealers and all interdealer brokers (except one) in order to provide better data availability and thereby greater transparency for the U.S. Treasury market. The GovPX data set consists of all trades and quotations that are transacted through participating interdealer brokers. It contains only the best bid and ask. In addition to trade prices, the size of the trade is also recorded as well as the side originating the deal (hit or take). There is no other data set for U.S. Treasury securities that covers a similarly extensive period of intraday quotes and trading activity. The GovPX data coverage starts in July 1991 and runs through to the most recently compiled period. Hence it provides a unique opportunity to researchers. This study uses data from 1 January 1994 to 31 December 2000. This includes data on over 4.5 million trades and approximately 50 million quotes for 829 securities[2] that include bills, notes and bonds.

Although the GovPX data set is unique in its coverage of the Treasury securities secondary market, it is important to point out some of its limitations. First, as mentioned above the data is from only five of the six interdealer brokers. It does not include trades and quotes routed through Cantor Fitzgerald who mainly focuses on the “long end” of the Treasury maturity spectrum. We do not expect this to bias the results of our particular study. Second, since the interdealer broker market is anonymous, it is impossible to identify the counterparties of a transaction or identify the brokers submitting quotations. Third, not all dealers' quotations are included in the data set but only those that improve the best bid or ask. The bid-ask

[2] There also exist cash management bills in the data, but they are of too short a maturity and are, automatically, never considered.

spread that can be inferred from the data is therefore considerably smaller than individual brokers' bid-ask spreads. Since the Treasury secondary market, however, is extremely competitive and very transparent, the best bid and ask seem to be a good representation of the actual trading costs incurred by dealers or their clients. Fourth, GovPX contains only trades and quotations that are placed via the interdealer broker system. This is potentially a serious drawback of the data set since any trades and quotes that are directly between dealers or between dealers and their customers are excluded. Given that the interdealer market is anonymous whereas for direct transactions between dealers or between dealers and clients the counterparties know who is "on the other side" of the transaction, the decision whether to use the former or latter way of transacting becomes a strategic choice.[3] If there is trading based on superior information, then this type of trading activity would more likely be transacted through the anonymous screen of an interdealer broker. Hence, there is an adverse selection problem particularly for interdealer broker transactions. This can have significant impact on relative prices as well as quotations between the two different transaction mechanisms. If dealers know that adverse selection risk is greater for interdealer broker transactions then they will quote worse prices on the screens and consequently bid-ask spreads would be larger for interdealer transactions than for direct transactions. Therefore, conclusions about liquidity and pricing effects that are based on observing interdealer trading and quoting activity alone have to be treated with some caution.

3.2 Repo Market

General collateral and special collateral repo quote data is available from GovPX Inc. Unfortunately, the data starts on 7th November 1995 i.e. does not cover the entire period for which cash market data is available. As Figure 2 shows, the overnight general collateral repo rate cointegrates and is of the same order of magnitude as the Fed Fund's Rate. So, for the period prior to 7th November 1995, the Fed Fund's Rate is used as a proxy.

3.3 Strip Market

Data on U.S. Treasury strips is obtained from Street Software and is used to estimate the returns from a benchmark portfolio.

3.4 Which prices to use?

The selection of pairs is performed in price (as opposed to return) space. Stable cointegration relationships between securities are desired. Since the strategy is based on actual trade prices it is important to use dirty rather than clean prices in both the training and, of course, the trading period. The GovPX data contains clean prices and so accrued interest is added to obtain dirty prices.[4]

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[3] See, for example, Barclay *et al* (2001), Conrad *et al* (2001) and Keim and Madhavan (1996).

[4] Often prices in bond markets are quoted "clean". The buyer must compensate the seller for the portion of the next coupon interest payment the seller has earned but will not receive

3.5 Frictions

3.5.1 Bid-Ask Spread & Commission

The median of the bid-ask spread for each day is used as a base. As argued above, the bid-ask spread in the GovPX data, are based on the best quotes in the interdealer market. However, as also argued above in Section 3.1, the bid-ask spread in the interdealer market would, in general, serve as an upper-bound for the bid-ask spread in the public-dealer trades that are being simulated in this chapter. If this strategy is implemented by dealers in the interdealer market, commissions are $10 per trade size of $1m i.e. approximately 0.1 basis points.[5] Public trades may have slightly higher commissions. We assume that the biases in estimating the magnitude of bid-ask spreads and commission in the public-dealer trades roughly offset each other.

3.5.2 Shorting and Financing Costs

Out of the approximately 60 to 80 securities (i.e. 30-40 pairs) in the subset of securities within a trading period, at most only two or three securities may be "on special".[6] It is more likely that those securities on special will be the ones that are shorted, as their prices will be higher in the cash market. So, it is not reasonable to assume, at the outset, that the pairs trader will be either paying or receiving the "specialness" for roughly equal periods of time. To simplify matters, for the purpose of this study, those securities that are on-the-run are excluded from the subset of securities used to form pairs. This allows us to use the general collateral repo-rate as the relevant rate when estimating the costs of financing positions. By construction, we thus also abstract away from the other popular trading strategy of shorting the on-the-run (dearer) security and going long the off-the-run (cheaper) security to earn that "apparent" spread[7].

The impact of movements in the prices of the long and short bonds on the repo margin payments is shown in Table 2. The security flow when margin is demanded can be cash, securities or both. For this study, cash is assumed to flow between counterparties and repo interest payment amounts are adjusted daily. The lender of the security usually applies the haircut. It protects her (Choudhry (1999)) against:

- a sudden fall in the market value of the collateral;
- illiquidity of collateral

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from the issuer because the issuer will send the next coupon payment to the buyer. This amount is called accrued interest and depends on the number of days from the last coupon payment to the settlement date. The accrued interest when added to the clean price gives the "dirty" price, the actual trade price. See Fabozzi (2000) for this and other details of bond markets in general.

5 We say "approximately" 0.1 basis points because 0.1 basis points is *exact* only for a bond priced at face value.

6 A bond is said to be "on special" when the repo rate for it is lower than the repo rate for all other bonds. The specialness is caused by an extreme supply demand imbalance.

7 The term "apparent" is used because as Krishnamurthy (2000) shows, once the repo market financing costs are allowed for, the profits are greatly diminished.

- other sources of volatility of value (e.g. approaching maturity)
- counterparty risk

  The pairs trader, is assumed to be perceived as a low risk counterparty. The securities traded are filtered to be those that are liquid. Also, the trader has equivalent repo and reverse-repo positions. So, the haircut, or initial margin is assumed to be zero.

4. The Proposed Trading Strategy

The generic trading strategy proposed is as follows. The length of all training periods and trading periods is fixed at the outset, at the start of 1994. Thus, pairs are always fixed once, at the start of a trading period, by looking back in time over the length of the training period. For each security, the "distance" between it and all other securities in the subset are calculated. The "distance" is defined as the sum of the square of the daily difference in normalised prices of the securities. The price used is the median[8] of the mid-quote for each day. The normalisation of prices for each security is done by subtracting the sample mean of the training period, and dividing by the sample standard deviation over the training period. A record is kept of the distribution of distances between each pair over the training period. During the trading period (see Figure 3), a pair is opened for trading when the distance between the securities in that pair widens to reach or cross a trigger level, defined as a percentile of the empirical distribution of distances observed over the training period. The trade is reversed when any of the following three (sufficient) conditions are met:

1. the spread narrows so that the distance between the securities in a pair reaches or crosses its median distance
2. the last day of the trading period is reached
3. the distance widens to hit a risk management trigger

The first condition, by construction leads to a profit. The second condition may lead to a profit or a loss. The third condition, a simple risk management tool, always leads to a loss. It models one or more of the following:

- the trader faces the risk that his model of the pair's relationship is flawed, or
- noise traders are temporarily forcing the "normal" historical relationship to be stretched beyond what the trader had expected ex-ante from his limited training period, and there is a fear that
  - margin payments may be demanded soon
  - credit lines may be cut
  - the owners of any equity capital are going to prefer to take a loss and close the position rather than risking riding what may not be a trough and lead to a larger loss of wealth

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[8] Wherever medians rather than means are used, the purpose is to avoid distortions in means caused by outliers without affecting the economic story or making the study unrealistic.

4.1 Selecting Pairs

The selection of pairs is made from a subset of securities for which there are at least ten quotes each day. Although this pre-selection rule to exclude many securities may seem ad hoc, it serves a useful purpose for this exercise. Pairs trading is usually carried out with the most liquid securities in a market. This pre-selection criterion helps to create this list automatically.

5. Simulation and Analysis[9]

The theme of this section is to present a few specific examples of the generic trading strategy, to appraise them, and to produce estimates for the effect of transaction costs and financing costs on the performance.

5.1 Simulation Parameters

For the kind of simulation exercise set out in this chapter, one could come up with an infinite number of distinct strategies by varying the various trigger levels and training and trading periods. However, the purpose of this study is not to suggest the optimal (ex-ante) strategy for the universe of securities available within the asset class. Therefore, for the purpose of this study, four cases of the generic trading strategy are used as illustrative examples. They can be defined by:

Name of Strategy	**P1505**	**P1510**	**P2005**	**P2010**
Training Period (days)	40	40	40	40
Trading Period (days)	40	40	40	40
Trade Opening Trigger (percentile)	15	15	20	20
Stop-Loss Trigger (percentile)	5	10	5	10
Trade Closing Trigger (percentile)	50	50	50	50

The ‘P’ in the strategy represents *P*airs Trading. The first two digits in the name represent the trade opening trigger percentile. The next two digits represent the stop-loss trigger percentile. Later benchmark strategies are devised which are named similarly, but starting with the letter ‘B’. The triggers shown, in fact, represent two levels about the median. Thus a pair opening to trade at a 15 percentile trigger, would also open to trade at a 65 percentile trigger, but with opposite positions in the constituents of the pair. Correspondingly, if this pair was opened to trade at 15 percentile (65 percentile) trigger, it would be closed if it hit the 5 percentile (95 percentile) stop-loss trigger.

[9] Unless specified otherwise, all significance tests are at 99 percent confidence, and significant t-stats are shown in **bold typeface** rather than *italics*

5.2 Expected Returns

For a given stop-loss trigger, say at 5 percentile, it is not immediately obvious whether a higher or lower trade opening trigger would produce the higher expected returns for a given pair. Working in terms of "percentiles", if we define "stop-loss hit" to be the event that the stop-loss trigger is hit and h_o*(stop-loss)* to be the probability of hitting the stop-loss trigger for a given trade opening trigger of o, we see that:

$$E(return_{\text{trade opening trigger} = o}) = E(return_{\text{trade opening trigger} = o} \mid \text{stop - loss not hit}) * (1 - h_o) + E(loss_{\text{trade opening trigger} = o} \mid \text{stop - loss hit}) * h_o$$

The two expectations on the right hand side are, of course linked since:

$$E(return_{\text{trade opening trigger} = o} \mid \text{stop - loss not hit}) + E(loss_{\text{trade opening trigger} = o} \mid \text{stop - loss hit}) = 50 - [\text{stop - loss trigger level}]$$

Also, the probability of hitting the stop-loss trigger h_o*(stop-loss)* is also directly related to the distance between the trade opening and stop-loss triggers. The table below summarises the key points.

Trade Opening Trigger Level	**Far from 50 (median)**	**Close to 50 (median)**
Trading frequency	Lower	Higher
Total Transaction costs	Lower	Higher
Profit from trade that does not hit stop-loss	Large	Small
Proximity to Stop-Loss	Close	Far
Stop-Loss activation	Sooner?	Later?
Loss when Stop-Loss activated	Lower	Higher

Eventually, it is the stochastic process followed by the price spread between the constituents of a pair that would drive the profit generation. Depending on the realised path of the spread, the trader may end up opening trades often, never hitting the stop-loss, and taking profits at the median. Or she may rarely open trades and, upon doing so, hit the stop-loss trigger frequently and lose money.

5.3 Benchmarking

In order to appraise the performance of the strategies, for each strategy a duration-matched benchmark is created using strips data. This hypothetical portfolio aims to capture the majority of the risk in the pairs trading strategy. When a reference level is required, for instance, for the Gain-Loss Ratio, this benchmark is used. In addition, zero and the risk-free rate are also used. A reference of zero represents the scenario where there is no financing required to implement this trading strategy i.e. repo and reverse repo trades effect the long and short positions, respectively, and margin payments are never demanded. The duration-matched benchmark returns are always computed without any transaction costs. As the duration-matched benchmark would incur the same level of transaction costs to implement, for fairness, the returns of the pairs trading strategy are also shown without transaction costs. The duration-matched benchmark for a pairs trading strategy with no transaction costs is very slightly different from the duration-matched benchmark for a pairs trading strategy with transaction costs. So, the benchmark returns are shown twice. For comparison, results, where appropriate, are also shown for the Salomon Brothers Treasury Index, the most widely used index for the US Treasury market. In addition and where appropriate, results are also shown for the S&P 500 Composite and the risk-free rate, represented by the Fed Funds Rate. The strategies P1505Z or P1505W are picked as the flagship strategies when making general comparisons of the pairs trading strategy with other investment strategies. The 'Z' and 'W' indicate returns without and with transaction costs, respectively.

5.4 Performance Analysis

5.4.1 Characteristic Features of the Traded Portfolio

Figure 4 shows the distribution of returns for the S&P 500, Salomon Brothers Treasury Index and the P1505Z strategy, along with their underlying normal distributions[10]. The pairs trading strategy has a much narrower range indicating limited upside and (risk management controlled) downside. Examining this strategy P1505Z more closely in Figure 5, we see that it is highly non-normal compared with, say, the S&P500, and there is a discontinuity in the returns distribution at zero.

Table 3 shows some of the characteristics of the return distributions for the various asset markets and pairs trading strategies. The pairs trading strategies can outperform the equity and bond index using the Sharpe Ratio. Examining the Gain-Loss Ratio, we see that the pairs trading strategies almost always outperform all the benchmarks. The correlations of the flagship strategies P1505Z and P1505W with the S&P500 and the Lehman Brothers Treasury Index are 0.05 and -.03, respectively.

5.4.2 Omega functions

Figure 6 shows the Omega[11] Function of Keating and Shadwick (2002) as a function of daily returns for the S&P 500, Salomon Brothers Treasury Index and the strategy P1505Z. For the Omega Function, the mean is represented by the point on the x-axis where the curve cross y=1. Figure 6 illustrates that although the upside relative to the mean is limited for the pairs trading strategy (steep curve above the mean), its risk-reward trade-off is enhanced by also limiting the downside (steep curve below the mean).

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10 The fitted normal distribution is one that has the same mean and variance as the underlying data.

11 The Omega Function is defined as $\Omega(L) = \dfrac{\int_L^b [1 - F(r)]dr}{\int_a^L F(r)dr}$ where (a, b) is the interval of realised returns, and F(r) is the cumulative distribution of returns.

Figure 7 shows the Omega Function for the strategy P1505Z along with that for its duration-matched benchmark portfolio. As can be seen from the graph, benchmarking vis-à-vis duration only ignores the other principal components of yield curve changes that can enhance returns.

Figure 8 shows the Omega Function for the four pairs trading strategies. Comparing them, see that P1510Z is preferred on the downside. On the upside, it is preferred to the other strategies for most of the range, but its upside is limited compared with P1505Z and P2005Z. This is because it hits its stop-loss trigger and is forced to close trades more often. The table below, measures returns in "percentile terms", and illustrates the point further.

Name of Strategy	P1505	P1510	P2005	P2010
Trade Opening Trigger (percentile)	15	15	20	20
Stop-Loss Trigger (percentile)	5	10	5	10
Trade Closing Trigger (percentile)	50	50	50	50
Profit from closing trade at median	35	35	30	30
Loss when Stop-Loss is activated	-10	-5	-15	-10
Proximity to Stop-Loss at open	10	5	15	10
Proximity to median at open	35	35	30	30

5.5 Enhancing Strategy Performance in Practice

In practice, returns could be enhanced by a number of simple tweaks:

- Pairs have been formed from the subset of *all* securities for which there are at least ten quotes per day. Instead, pairs that are not really well cointegrated may be excluded for trading. This could be implemented by imposing one or more restrictions on the distribution of the distances between pairs that are selected.
- In the simulations, all open pairs are forced to close on the last day of each trading period. In practice, a marked improvement in returns could be had from being selective about which positions are closed. The others could be allowed to run for longer.
- In the simulation, pairs are selected by examining the distribution of distances between securities. It is possible that, using this method, a pair is selected with constituents that appear to be closely cointegrated but are in fact diverging. If this is the case, they may open trading as soon as the trading period commences. However, the P&L is highly likely to worsen as time progresses with a large loss realised, either on the last day of the trading period, or by the setting off of the risk-management trigger. This is illustrated in Figure 7. A time-series analysis of the spreads between securities may enhance returns considerably.

Excluding bonds which pay coupons during the training and trading period may improve performance as the pairs formation may be more accurate[12].

6. Conclusion

The simple pairs trading strategy suggested performs well relative to various benchmarks and using different measures of performance. Even as an unsophisticated strategy it allows a trader to benefit from any predictability in spreads between bonds and short-lived mis-pricing of bonds.

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[12] Using clean prices during the training period, and (by definition) dirty prices in the trading period produced terrible results (not reported), indicating the importance of using "real prices".

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Tables

	US Equities	US Treasury Securities
Trading Costs (bid-ask spread and broker commission)	higher	order of magnitude lower
Cointegration	low	high
Security lifetime	high	low to high
Potential "learning period"	long	short to medium
Idiosyncratic Risk & E(Return) i.e net spread risk and unleveraged E(returns)	high	low
Unleveraged VaR	high	low
Normal levels of risk driven by	company specific events or announcements	sustained micro distortions in term structure
Extreme risk probably caused by	company distress	worsening micro distortions in term structure.
Leverage costs (collateral risk)	high	low
Shorting:		
- **ease**	lower	higher
- **costs**	higher	lower
- **social acceptance**	can be low	less affected
Price pressure per $ traded	Higher	lower
Idea of efficient price	Difficult to assess	relative pricing has stricter bounds
Do we understand exactly how efficiency is maintained?	no	no
Trading activity levels	sufficient for the more liquid securities	for off-the-run securities can be unpredictable
No of available securities	large and stable	smaller and depends on government's funding requirements and policy
Dealing with dividends/coupons	jump on ex-dividend date	although clean prices are smooth, need to work with dirty prices with jumps on ex-dividend date
Possible benchmark	Contrarian strategies	duration matched portfolio

Table 1: Pairs Trading in Equity vs Bond Markets

	Long Position Financing Lend bond Borrow cash Pay repo rate	Short Position Financing Borrow bond Lend cash Receive repo rate	Spread Trade P&L	Repo Margin Cashflow Direction
Long ⇑ = Short ⇑	Collateral has gone up Can ask for: more cash and pay more repo interest or - ask for some bonds back to use as collateral elsewhere	Collateral has gone up May be asked to: - deposit variation margin but receive repo interest on that too or - to return some of the bond	No effect	-
Long ⇑ > Short ⇑	Collateral has gone up (more than short) Can ask for: more cash and pay more repo interest or - ask for some bonds back to use as collateral elsewhere	Collateral has gone up (less than long) May be asked to: - deposit variation margin but receive repo interest on that too or - to return some of the bond	Small profit	To trader
Long ⇑ < Short ⇑	Collateral has gone up (less than short) Can ask for: more cash and pay more repo interest or - ask for some bonds back to use as collateral elsewhere	Collateral has gone up (more than long) May be asked to: - deposit variation margin but receive repo interest on that too or - to return some of the bond	Small loss	To Repo Dealer
Long ⇓ = Short ⇓	Collateral has gone down May be asked to: - return cash and so pay less repo interest or - to provide more bonds	Collateral has gone down Can ask for: - some cash back but then receive less in repo interest amount or - for more bonds and use as collateral elsewhere	No effect	-
Long ⇓ > Short ⇓	Collateral has gone down (more than short) May be asked to: - return cash and so pay less repo interest or - to provide more bonds	Collateral has gone down (less than long) Can ask for: - some cash back but then receive less in repo interest amount or - for more bonds and use as collateral elsewhere	Small loss	To Repo Dealer

Long $\Downarrow$ $<$ Short $\Downarrow$	Collateral has gone down (less than short) May be asked to: - return cash and so pay less repo interest or - to provide more bonds	Collateral has gone down (more than long) Can ask for: - some cash back but then receive less in repo interest amount or - for more bonds and use as collateral elsewhere	Small profit	To trader
Long $\Uparrow$ Short $\Downarrow$	Collateral has gone up Can ask for: - more cash and pay more repo interest- or - ask for some bonds back to use as collateral- elsewhere	Collateral has gone down Can ask for: - some cash back but then receive less in repo interest amount or - for more bonds and use as collateral elsewhere	Profit	To trader
Long $\Downarrow$ Short $\Uparrow$	Collateral has gone down May be asked to: - return cash and so pay less repo interest or - to provide more bonds	Collateral has gone up May be asked to: - deposit variation margin but receive repo interest on that too or - to return some of the bonds	Loss	To Repo Dealer

Table 2: Profit & Loss, Repo Financing

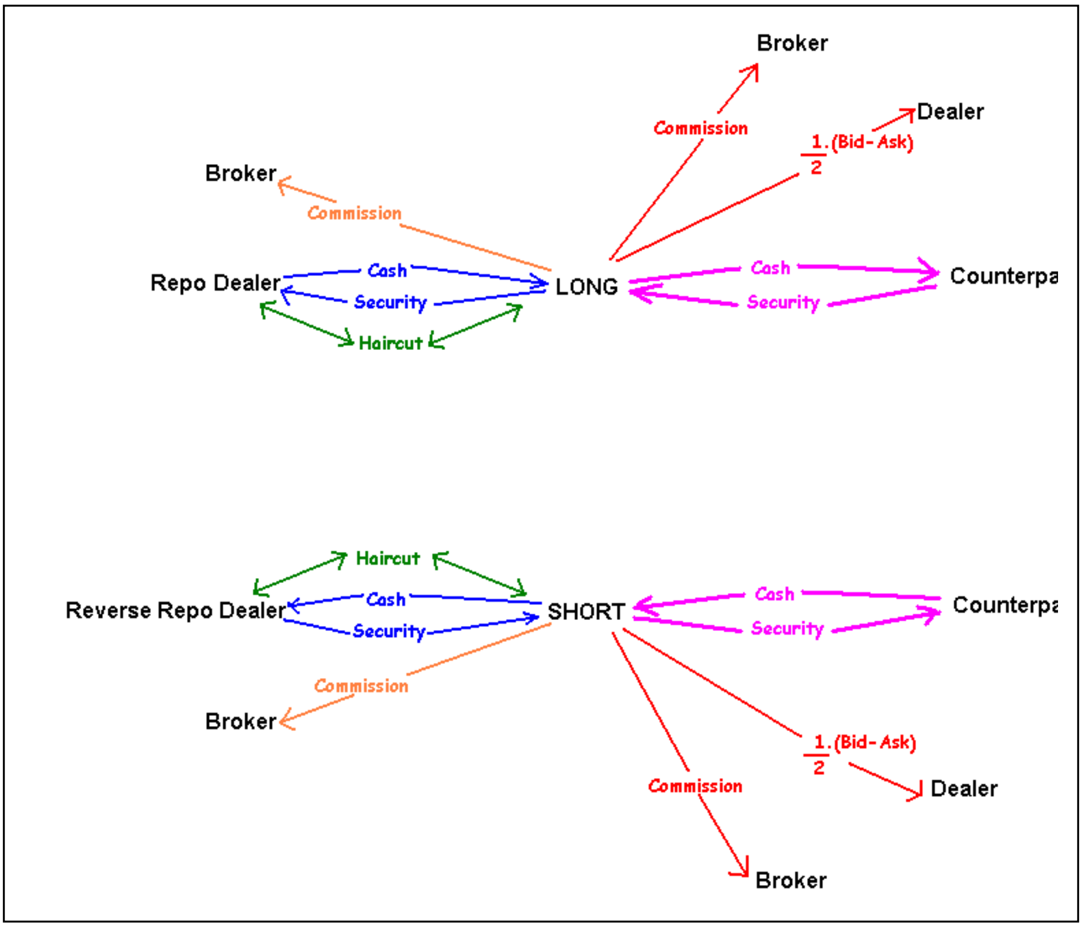
	Risk free	S&P500	Salomon	P1505Z	B1505Z	P1505W	B1505W	P1510Z	B1510Z	P1510W	B1510W	P2005Z	B2005Z	P2005W	B2005W	P2010Z	B2010Z	P2010W	B2010W
Nobs	1638	1638	1638	1638	1638	1638	1638	1638	1638	1638	1638	1638	1638	1638	1638	1638	1638	1638	1638
Mean	1.44	5.07	2.41	2.05	1.41	1.43	1.41	1.87	1.29	1.32	1.29	1.49	1.42	0.84	1.42	1.11	1.35	0.54	1.35
std error	0.004	2.21	0.61	0.12	0.06	0.12	0.06	0.12	0.10	0.11	0.10	0.12	0.07	0.11	0.07	0.10	0.07	0.10	0.07
Minimum	0.82	-384.34	-152.72	-11.16	-17.95	-12.18	-17.93	-9.84	-40.95	-11.09	-40.95	-28.86	-22.66	-31.01	-22.67	-28.86	-22.20	-31.01	-22.20
Standard dev.	0.17	89.43	24.66	4.83	2.56	4.68	2.56	4.70	4.21	4.52	4.22	4.73	2.70	4.46	2.70	4.20	2.83	4.08	2.83
1st quartile	1.37	-34.76	-9.56	0.00	0.00	-0.23	0.00	0.00	0.00	-0.20	0.00	0.00	0.00	-0.41	0.00	0.00	0.00	-0.37	0.00
Median	1.46	4.57	1.25	0.52	1.24	0.04	1.23	0.29	1.00	0.00	1.00	0.39	1.25	0.00	1.25	0.25	1.21	0.00	1.21
3rd quartile	1.53	47.24	15.05	2.17	2.03	1.39	2.03	1.56	1.84	0.93	1.84	1.68	2.07	0.91	2.06	1.26	2.01	0.60	2.00
Maximum	2.06	511.52	91.48	55.51	28.89	53.74	28.89	51.03	118.85	48.58	118.93	55.51	28.89	43.26	28.89	44.95	29.33	43.26	29.33
Skewness	-0.57	0.06	-0.15	3.82	1.76	3.84	1.76	4.55	13.70	4.57	13.72	3.05	0.94	2.23	0.94	1.97	1.22	1.58	1.22
Kurtosis	4.28	6.29	5.49	24.99	24.91	25.72	24.89	29.53	389.79	30.11	390.33	30.13	25.17	23.69	25.16	28.03	26.42	28.91	26.43
Sharpe Ratio		0.04	0.04	0.13	-0.01	0.00	-0.01	0.09	-0.04	-0.03	-0.04	0.01	-0.01	-0.13	-0.01	-0.08	-0.03	-0.22	-0.03
Gain-Loss RF		1.02	1.15	3.52	1.46	3.06	1.46	4.14	1.54	3.57	1.54	2.70	1.42	2.56	1.43	2.53	1.43	2.45	1.43
Gain-Loss Z		1.00	1.05	1.97	1.88	3.54	1.88	4.15	1.62	5.47	1.62	1.32	1.76	2.30	1.74	0.96	1.67	2.14	1.67
Gain-Loss B				1.63		1.62		1.56		1.55		1.25		1.25		1.08		1.08	

Risk free = Federal Funds Rate
Salomon = Salomon Brothers Treasury Index
P = Pairs trading
B = Benchmark (duration matched)
Z = with no transaction costs
W = with transaction costs
-*1505*- = 15 percentile opening trigger, and 5 percentile stop-loss trigger
Returns shown are in basis points and are daily returns.

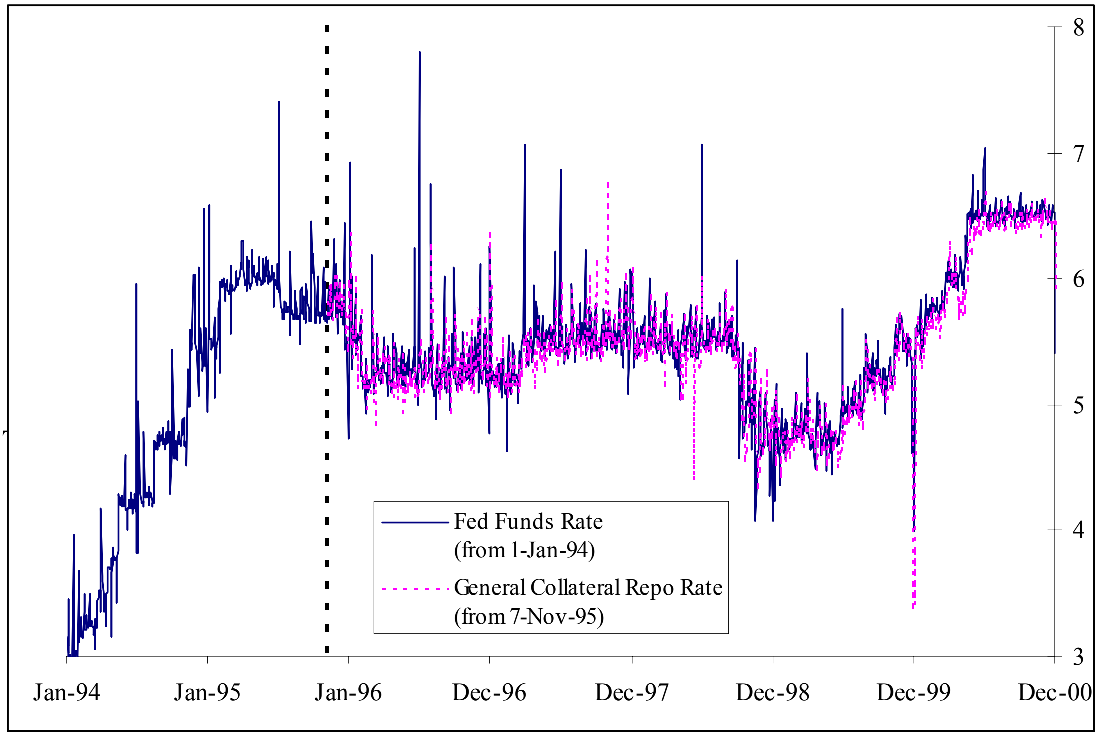
Gain-Loss RF = Gain-Loss Ratio calculated with the risk-free rate as the reference
Gain-Loss Z = Gain-Loss Ratio calculated with zero as the reference
Gain-Loss B = Gain-Loss Ratio calculated with Benchmark (duration matched) as the reference

Table 3: Comparing Different Strategies

Figures



Broker
Dealer
Commission
1.(Bid-Ask)
2
Broker
Commission
Cash
Repo Dealer
LONG
Cash
Counterpa
Security
Security
Haircut
Haircut
Cash
Cash
Reverse Repo Dealer
SHORT
Counterpa
Security
Security
Commission
Broker
1.(Bid-Ask)
2
Commission
Dealer
Broker



8
7
6
5
4
3
Fed Funds Rate
(from 1-Jan-94)
General Collateral Repo Rate
(from 7-Nov-95)
Jan-94
Jan-95
Jan-96
Dec-96
Dec-97
Dec-98
Dec-99
Dec-00

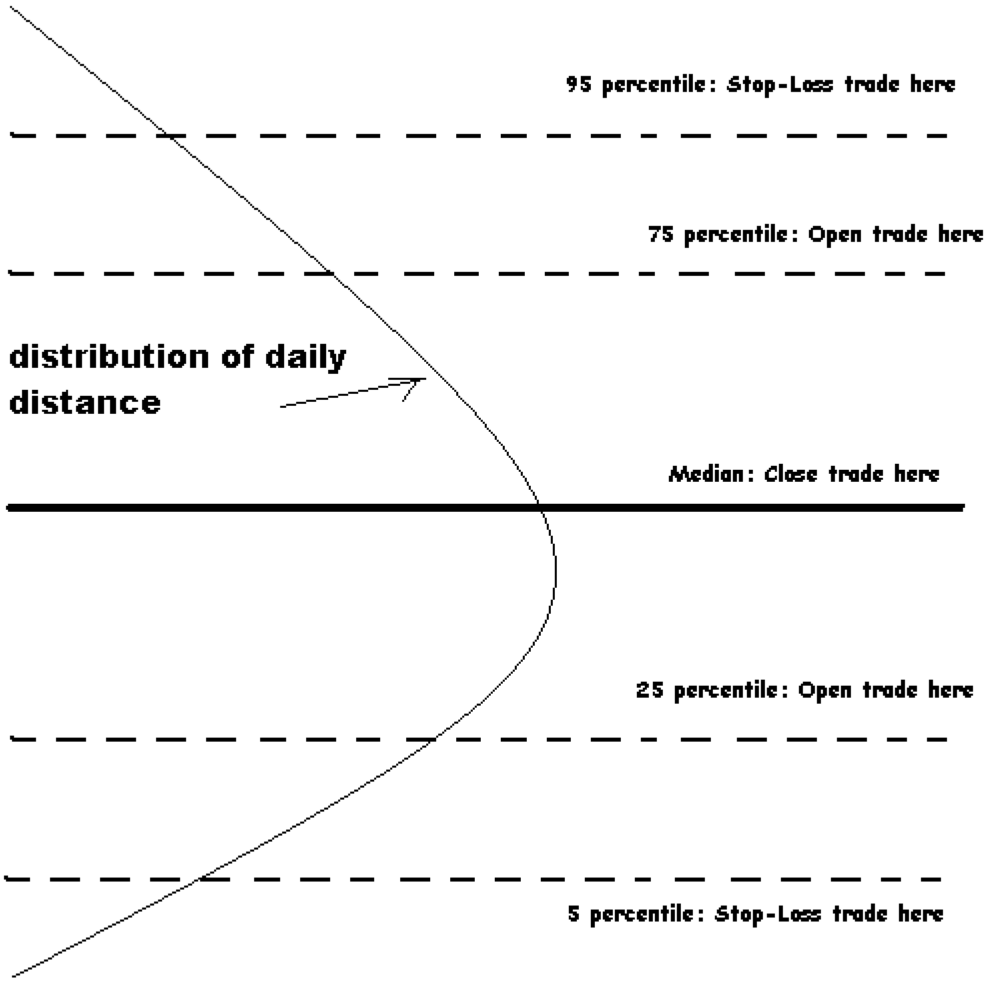


Figure 3: Generic Trading Strategy

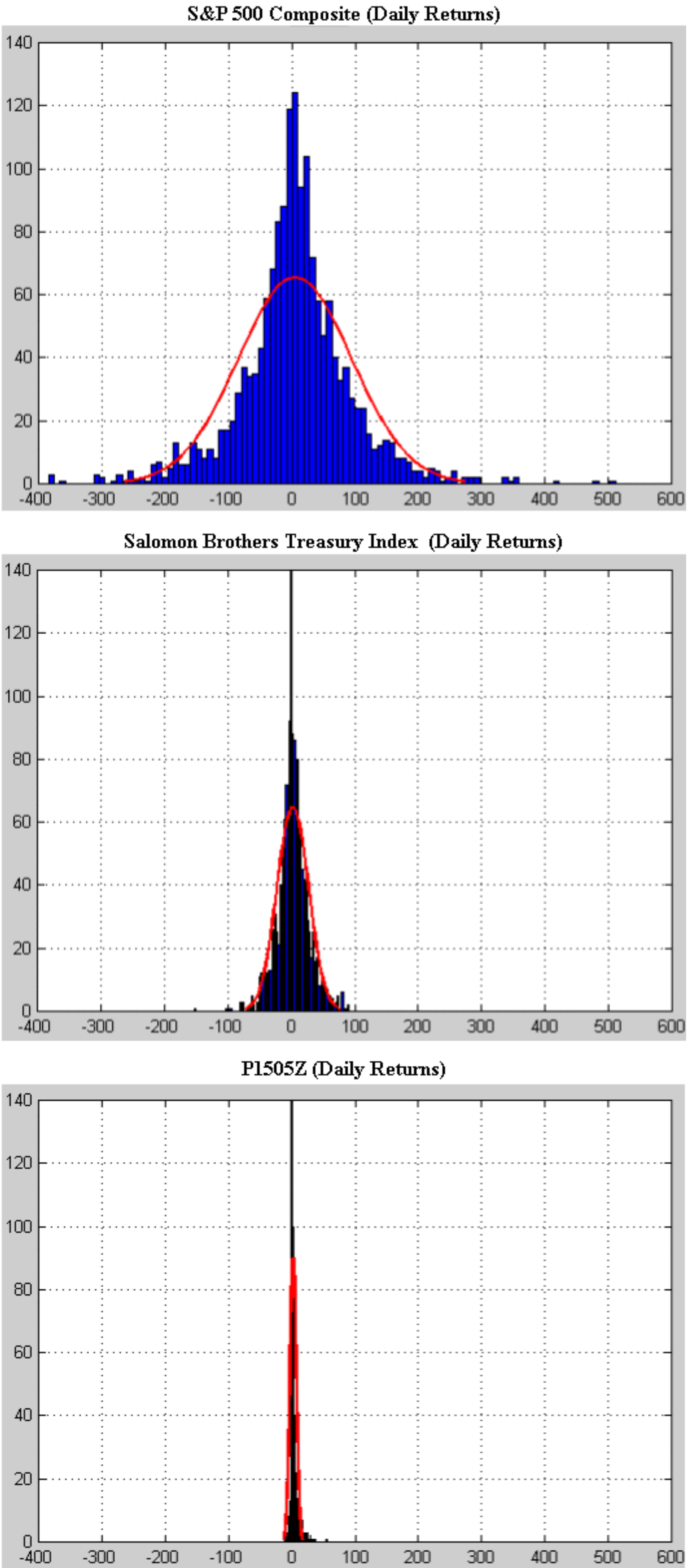


Figure 4: Returns Distributions

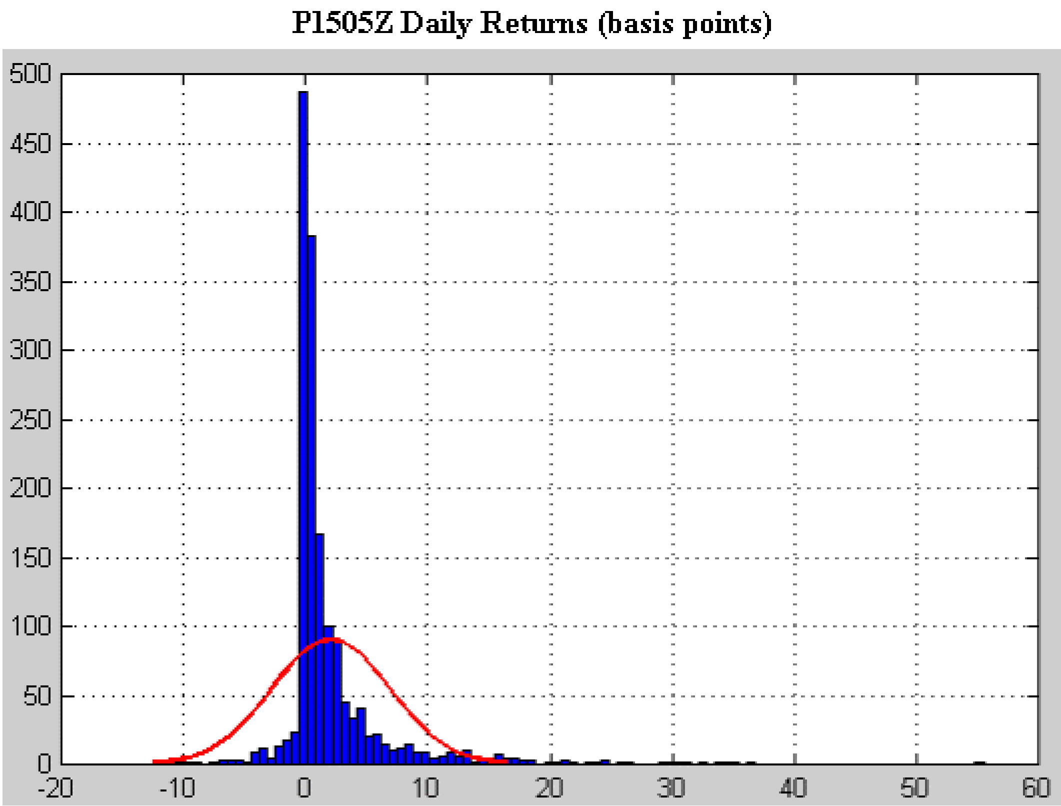


Figure 5: Returns Distribution for P1505Z

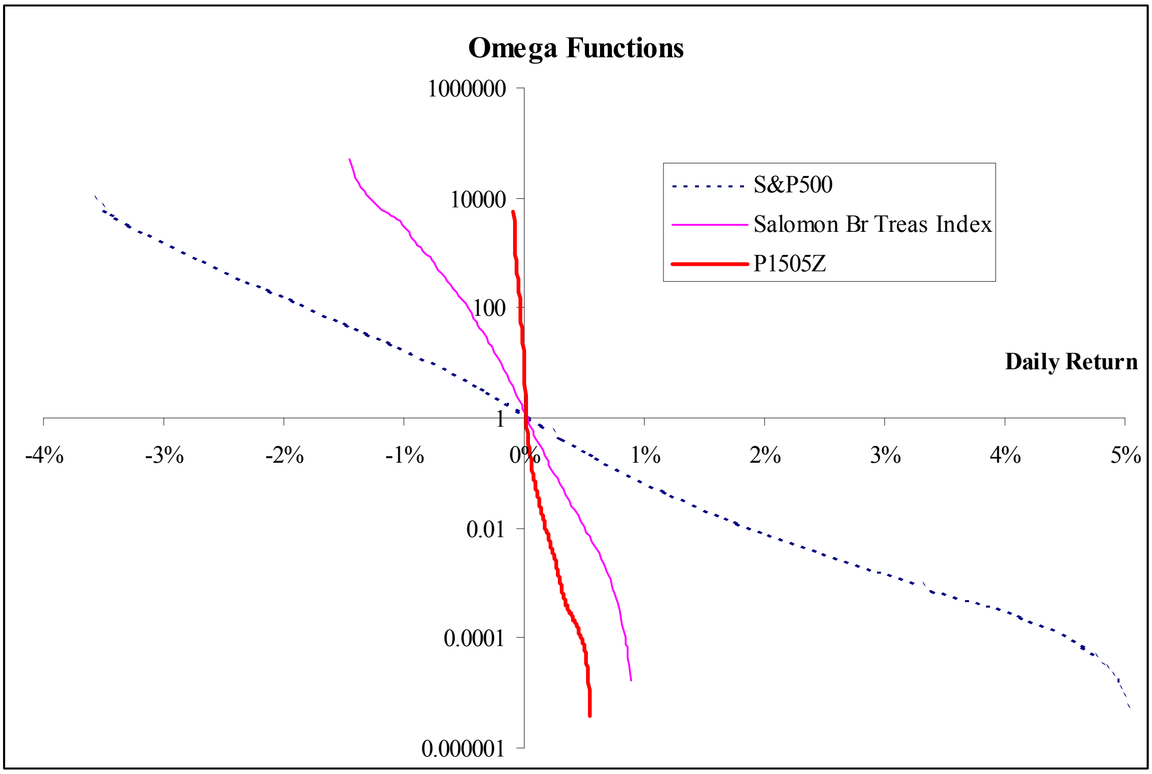


Figure 6: Omega Function

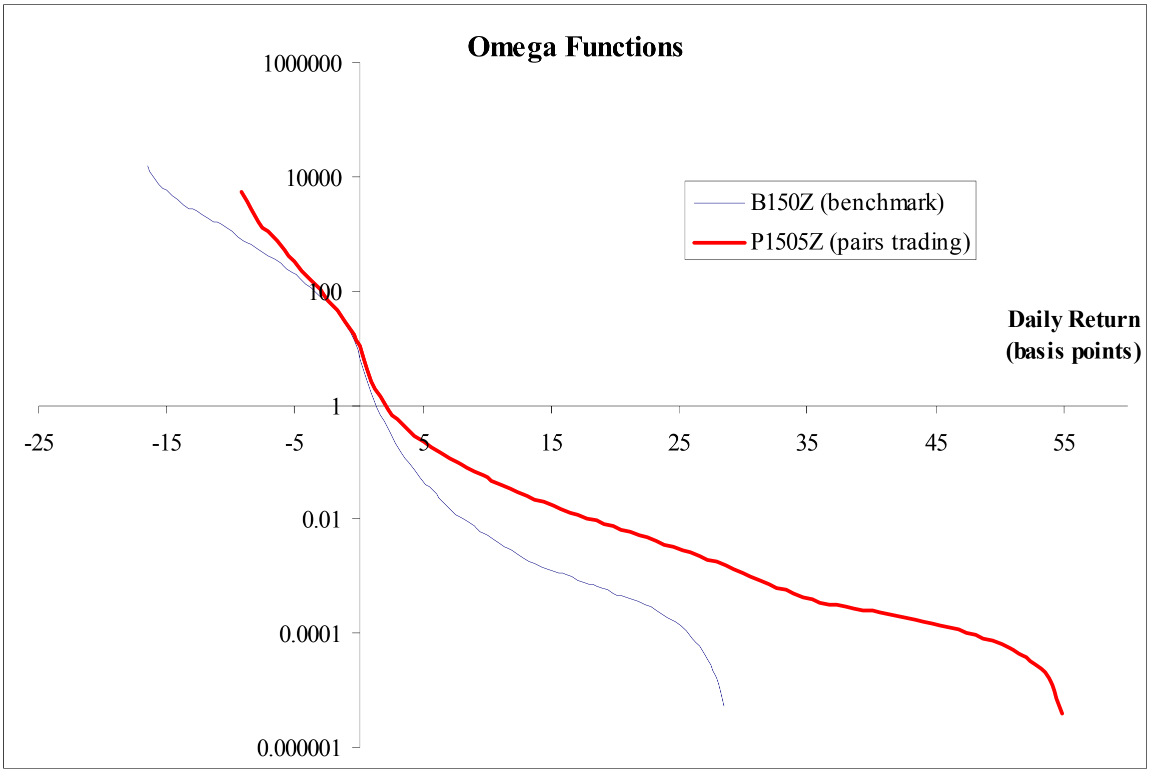


Figure 7: Omega Function, P1505Z vs Benchmark

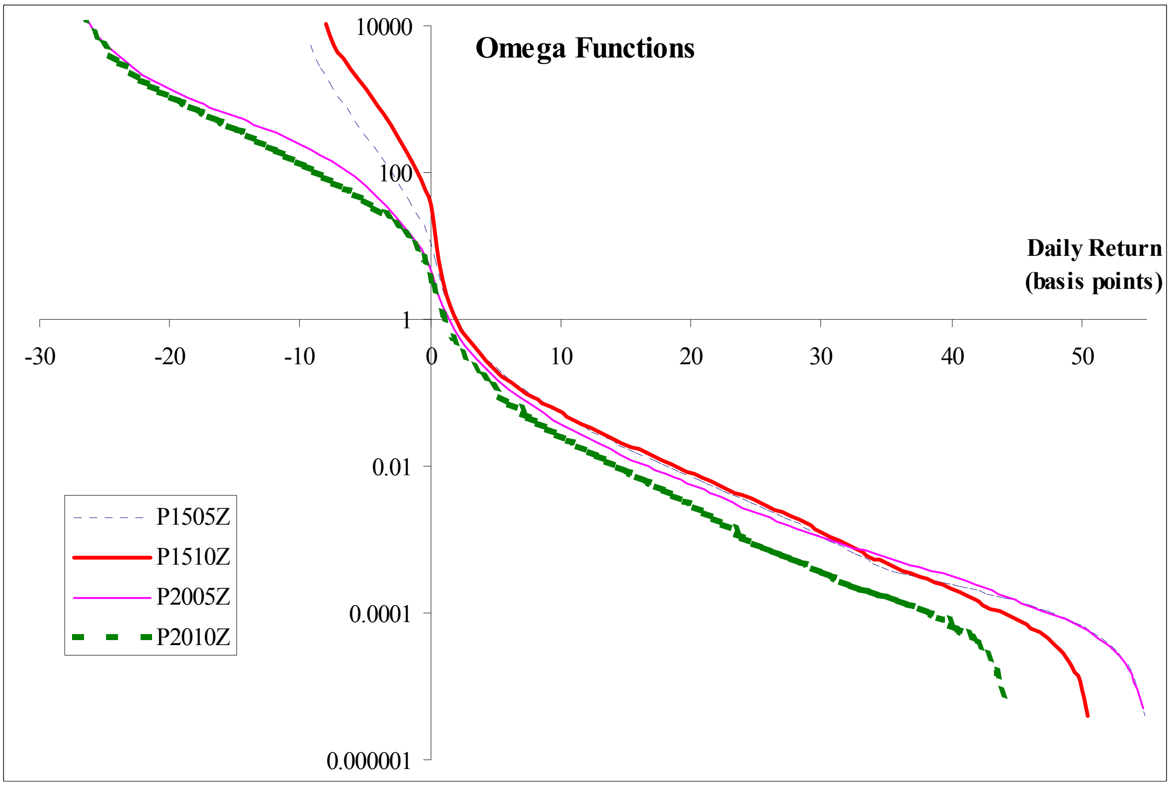


Figure 8: Omega Function for Pairs Trading Strategies

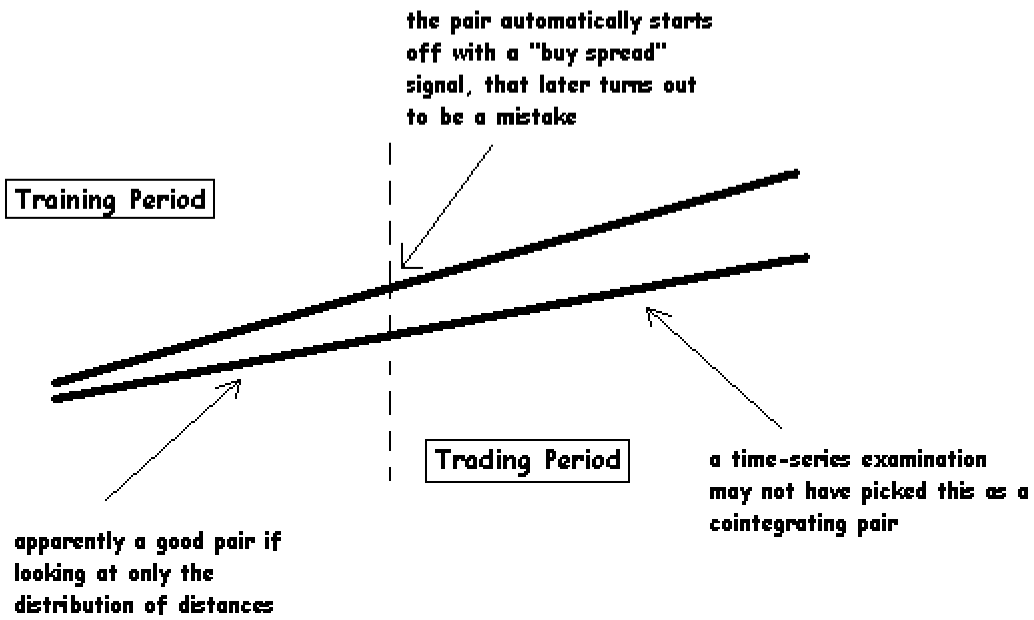


Figure 9: Problems with Simple Pairs Selection