Limits to Arbitrage and Commodity Index Investment: Front-Running the Goldman Roll

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ABSTRACT

This paper studies the unique rolling activity of commodity index in futures markets and shows that the resulting price impact is statistically and economically significant. Two trading strategies, devised to exploit this anomaly, yielded excess returns with positive skewness and Sharpe ratios as high as 4.39 from 2000 to March 2010. The profitability of the strategies is positively correlated with the net result of two opposite forces: the size of index investment and the amount of arbitrage capital employed. Due to the price impact, investors forwent 3.6% annual return, 48% higher Sharpe ratio, and billions of dollars over the period.

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Arbitrage is the basis of the efficient market hypothesis, as in theory, rational arbitrageurs can engage in risk-less arbitrage to quickly eliminate any market anomalies. In reality, many empirical evidence show that an anomaly can exist and sometimes persist for a long time, because both arbitrage opportunity and arbitrageurs are often limited, causing arbitrage capital to be slow-moving. Shleifer and Vishny (1997) show that market is often incomplete, so an arbitrage opportunity is usually not really risk free. They also point out that arbitrageurs are often capital constrained because of the agency problem. Abreu and Brunnermeier (2002) propose that arbitrageurs face synchronization risk due to the heterogeneity and preference to time the market rather than correct mispricing immediately, which leads to delayed arbitrage. Duffie (2010) suggests that a market anomaly can also persist due to arbitrageurs' inattention to the market.

Many empirical evidence on limits to arbitrage is found to be related to index investment. The most well-known example is the inclusion and exclusion effect of equity index. Petajisto (2011) shows that during the period 1990-2005, prices increased an average of 8.8% around the event for stocks added to the S&P 500, and dropped -15.1% if the stocks were deleted from the index[1]. The effect generally grows with the size of index fund assets. Besides that, Kaul, Mehrotra and Morck (2000) find that when the index increases the weights of stocks, prices experience significant increases during the event week with no reversal afterwards, even when the adjustment is previously announced. These anomalies exist mainly because index funds have to follow very mechanical trading rules in order to track the index, while there are not enough arbitrageurs in the market to absorb the price impact. In this paper, I extend the research into commodity index investment, which is attracting more and more attention from legislators, investors and economists.

Commodity index investment experienced dramatic growth over the last decade and now constitutes a significant fraction of investment in commodity futures markets. When commodity prices reached dizzying heights in mid-2008, the value of total long positions held by index investors reached $256 billion, up from about $6 billion in 1999. The average estimated ratio of these long positions relative to total open interests increased from 6.7% in 1999 to 44% in mid-2008 across 19 largest commodity markets that are covered by this paper. After the commodity prices collapsed in

[1] Other studies of effects include Harris and Gurel (1986), Shleifer (1986), Lynch and Mendenhall (1997), Chen, Noronha and Singal (2004), and many others.

the fall of 2008, investment dropped, but it quickly rebounded. The value of index investors' long positions almost doubled from $112 billion to $211 billion at the end of 2009, and the average estimated market ratio also increased from 39% to 52%. While there has been a heated debate on the impact of this surge in investment on commodity price levels[2], this paper investigates the impact from a different angle and focuses on a unique feature of commodity index investment. Unlike equity index funds that invest directly in the underlying assets, commodity index funds obtain price exposure by entering long positions in futures contracts. In order to maintain the long exposure, the funds need to unwind the maturing contracts before they expire and initiate new long positions in contracts that have later maturity dates. Since the funds have to roll their *entire* positions forward on regular basis, the potential pressure on the prices of contracts involved can be very large given the size of investment. This rolling activity gives investors a return called "roll yield", which refers to the difference between log price of the maturing contract they roll from and the deferred contract they roll into. Little attention of economists has been devoted to the impact of index investment on this separate, but quantitatively as least as important, component of total return.

This paper documents that the mechanical rolling forward of futures contracts explicit in commodity index funds' investment strategies exerts large and time-varying price pressure on the relative prices of the contracts involved in the rolling in the largest commodity markets. The price impact presents a big market anomaly and great trading opportunity. With very simple front-running strategies, the arbitrageurs can generate excess returns with positive skewness and annual Sharpe ratios as high as 4.39 over the period from January 2000 to March 2010. From the perspective of investors, the estimated losses due to this price pressure, amounted to about $26 billion over the period from 2000 to 2009, compared to the estimated total management fees of about $5 billion. Commodity index investors also forwent on average 3.6% annual return and a 48% higher Sharpe ratio over this period. The magnitude of this economic loss dwarfs the cost of price impact in the S&P 500 equity index due to the inclusion and exclusion effect, which is about 0.21-0.28% each year according to the estimation of Petajisto (2011).

[2]See Singleton (2011), Master and White (2008), Buyuksahin and Harris (2011), Hamilton (2009), Kilian (2009), Stoll and Whaley (2010).

The Standard and Poor's-Goldman Sachs Commodity Index (SP-GSCI) was the first commercially available commodity index and is also most popular one. The SP-GSCI rolls futures forward from the fifth to the ninth business day in each month, and its rolling activity is usually called the *Goldman roll* by practitioners. To help understand the Goldman roll and its impact, I use crude oil (WTI) as an example and look at a 15-business-day window ending on February 13, 2001. The SP-GSCI rolled the futures forward from February 7 to February 13 by shorting the March contracts and longing the April contracts. Panel A of Figure 1 shows the term structure of crude oil futures on February 7. As we can see, the slope was negative, which means contracts with shorter maturities were trading at premiums. This kind of term structure is called in *backwardation* in the literature. Because the March contract was more expensive, by shorting the March contract at $31.27 and longing the April contract at $30.98, the investors got a positive roll yield $ln(31.27/30.98) = 0.93\%$.

[Insert Figure 1]

Panel B of Figure 1 shows how the two contracts' prices moved during the 15-day window. Although the two contracts shared the same general price pattern, their prices were much closer during the rolling period. The difference between the prices of two contracts is called the *spread.* As shown in Panel C and Panel D, the spreads and roll yields were much lower in the rolling period. More importantly, we can clearly observe a large $0.31 drop in spread and a 1.1% drop in roll yield when entering the rolling period. This suggests that due to the large size of index investment, the shorting demand exerted by the Goldman roll caused the March contract to be temporarily underpriced, and the longing demand caused the April contract to be temporarily overpriced. The price pressure caused the roll yield to drop, resulting a loss for investors.

The plots also indicate how this mispricing due to the price impact can be easily exploited by long-short strategies. For example, on January 24, we can short the March contract at $29.05, anticipating that it would be relatively underpriced after 10 days. At the same time, we long the April contract at $28.31, expecting it to be relatively overpriced when the Goldman roll happens. In this way, we create a calendar spread position with net value equal to the spread $0.74, and this spread position has little exposure to the change in absolute level of crude oil price. When the mispricing happens on February 7 due to the Goldman roll, we unwind the positions by longing the March contract and shorting the April contract to exactly offset the positions of the SP-GSCI, paying the spread \$0.29. This front-running strategy profits from the drop in the spread \$0.74−\$0.29=\$0.45, and if we post full collateral for the spread position: \$28.68 ($=\frac{\$29.05+\$28.31}{2}$), the strategy yields an unleveled excess return of 1.57% in 10 days. In real world, initiating such a spread position only requires 2-4% margin of the nominal value, so the strategy can be easily implemented with very high leverage. As indicated by the plots, even if we front-run the Goldman by just a few days, the excess return can still be very high.

The paper investigates 19 commodities in the SP-GSCI that are traded on US exchanges. They have the largest and also the most liquid commodity futures markets, with a total weight of 93.22% in the SP-GSCI in 2010. The sample period is from January 1980 to March 2010. The year 2000 is set as a cut-off point, because index investment was nonexistent or very small (less than \$6 billion) before 2000. Two simple trading strategies, like the one above, are designed to exploit the price impact. The only difference is that Strategy 1 front-runs the Goldman roll by 10 business days, while Strategy 2 front-runs it by just 5 business days.

The 19 commodities are grouped by sectors to form 4 equally weighted sector portfolios (agriculture, livestock, energy and metals) and one total portfolio. In the period 1980-1999, the portfolios' Sharpe ratios were typically low or negative. However, in the period 2000-2010, both strategies yielded very high abnormal returns. Under the assumption that capital was invested in risk-free assets when it was not utilized for the strategies, the annualized Sharpe ratios ranged from 1.09 to 2.75 with Strategy 1 and from 0.46 to 1.78 with Strategy 2. More importantly, the excess returns were positively skewed for most portfolios, with a maximum skewness of 2.23 with Strategy 1 and 2.45 with Strategy 2. Energy sector is overall the best performing sector. With Strategy 1, the energy portfolio has unleveled annual excess return of 4.43%, with Sharpe ratio 2.2, skewness 0.88 and maximum drawdown only 0.94%. From the perspective of a money manager who has multiple trading opportunities and only cares about performance in the trading periods, the annualized Sharpe ratios ranged from 2.0 to 3.99 with Strategy 1 and from 1.16 to 4.39 with Strategy

2.

When the same strategies are applied to a control group of 18 commodities not included in the SP-GSCI, there were no abnormal returns earned in either period. The Sharpe ratios of similar portfolios were either negative or very small, with a maximum of 0.31. Results from panel regressions show that the average excess returns of both strategies were not significantly different from 0 for either commodities out of the SP-GSCI over the full sample period, or commodities in the SP-GSCI before the launch of the index (or the commodities' inclusion into the SP-GSCI). After the inclusions, the average excess return was 0.35% with Strategy 1 and 0.24% with Strategy 2. Both are statistically significant at the 1% level.

All information about the Goldman roll is publicly available. What is more, compared to the equity market, there are fewer barriers for arbitrage in commodity futures markets. There is no short-sell constraint. Anyone can enter into both long and short positions freely. High leverage can be easily obtained through low margin requirements. The commodities in the SP-GSCI have very liquid futures markets, and the contracts involved in the Goldman roll are also the most liquid contracts in each market. If the market was well arbitraged, we would not observe this market anomaly. However, the performances of the strategies indicate that the arbitrage capital is slow-moving.

Commodity Futures Trading Commission (CFTC) publishes weekly Commitment of Traders (COT) reports, which report the number of positions held by different traders in futures markets from 1986. I find little increase in the number of spread positions held by speculators before 2004 in 17 markets that have data available, which indicates that very few arbitrageurs were exploiting the market anomaly before 2004. It can be due to the inattention of arbitrageurs to commodity markets and thus their unawareness of this market anomaly. From 2004, the number of spread positions held by speculators has experienced a dramatic jump in all 17 markets, which suggests that as commodity markets and commodity index investment gained more attention and popularity from the investment community, more arbitrageurs were becoming aware of this market anomaly, and more arbitrage capital was utilized to exploit the price impact. Consistent with the limits to arbitrage theory, the paper shows that the performances of front-running strategies are significantly related to the net forces of the size of index investment and size of arbitrage capital utilized to take advantage of the market anomaly. The arbitrage profit is lower when there is a reduction in index investment or an increase in arbitrage capital.

A related work is the paper of Acharya, Lochstoer and Ramadorai (2010), who show that limits to arbitrage by speculators generates limits to hedging by producers, and affects both futures and spot commodity prices. The paper is also related to a classic theory called the *Theory of Normal Backwardation* (Keynes (1930), Hicks (1939) and Cootner (1967)) in commodity markets. The theory emphasizes the interaction between speculators and hedgers. Speculators earn a risk premium by taking opposite positions to meet the hedging demand of hedgers. Empirical evidence[3] shows that the risk premium is higher when the hedging demand is higher. Normally, commodity producers are the hedgers, taking short positions to hedge their productions, and commodity indices are originally designed to capture the risk premium of taking the long positions, so index investors are sometimes called index speculators. However, since index funds have to follow the exact rolling rules of the indices they track in order to minimize the tracking error[4], they have great hedging demand when they roll contracts forward. By meeting this hedging demand, speculators can earn very high excess returns.

The paper is organized as follows. Section 2 describes some facts about commodity index investment and the Goldman roll. Section 3 presents the empirical analysis and analyzes the performance of the front-running strategies. Section 4 concludes.

I. Commodity Index Investment

Commodity index investment has become increasingly popular among institutional and individual investors in recent years. The first commercially available commodity index was launched at the end of 1991, and now there are hundreds of different indices. Institutional investors, such as pension funds and endowment funds, usually enter into over-the-counter (OTC) swaps with big banks.

[3]See Carter, Rausser and Schmitz (1983), Chang (1985), Bessembinder (1992), de Roon, Nijman and Veld (2000) and Acharya, Lochstoer and Ramadorai (2010).

[4]Index funds also have no incentive to deviate from the fixed trading rules, because they received fixed management fees.

In a typical swap agreement, the investor pays the 3-month Treasury-bill rate plus a management fee to a Wall Street bank, and the bank pays the total return on a particular commodity index. The management fee ranges from 0.5% to 1.5% per year depending on the index and nominal amount. In order to hedge themselves, banks will take positions in futures contracts to replicate the index. Institutional investors can also put their funds under the management of a commodity index fund, which tracks a particular index. For individual investors, the main investment channel is exchanged-traded funds (ETFs) and notes (ETNs) which are tied to particular indices. The management fees associated with ETFs or ETNs are typically higher than the fees of swaps. Like other index investors, commodity index investors are usually long-term investors and mostly passive in the sense that there is no attempt to time the market or identify under-priced commodities. Most of the indices only take long positions in futures contracts[5], and all the positions are fully collateralized, with the collateral invested in 3-month Treasury bills.

The Standard and Poor's-Goldman Sachs Commodity Index (SP-GSCI) and the Dow Jones-UBS Commodity Index (DJ-UBSCI) are the two most popular commodity indices and used as industry benchmarks. According to Masters and White (2008), the estimated market share was approximately 63% for the SP-GSCI and 32% for the DJ-UBSCI in 2008. The SP-GSCI was the first commercially available commodity index and was launched in November 1991. It includes 24 commodities now, and the composition has remained the same since 2002. The DJ-UBSCI was launched in July 1998 and includes 19 commodities, 18 of which it shares with the SP-GSCI. The weighting schemes of the two indices are different. The weights in the SP-GSCI are primarily based on the delayed five-year rolling averages of world production quantities, while the DJ-UBSCI chooses weights based on liquidity and world production values, where liquidity is the dominant factor. The DJ-UBSCI also imposes lower bound of 2% for individual weight and upper bound of 33% for sector weight. Since the SP-GSCI is more popular and includes almost all commodities in the DJ-UBSCI and other indices, I will focus on the 19 commodities in it that are traded on US exchanges[6]. These commodities also have the largest futures markets, and will be referred

[5]Starting from 2006, some new commodity indices take both long and short positions depending on the term structures and other factors, like the Morningstar long and short commodity index. However, the majority of commodity indices still only take long positions.

[6]I exclude 5 industrial metals that are traded on London Metal Exchange (LME), because the maturity structure of

to as *index commodities*. Table I lists these commodities and their weights in the two indices in 2010[7]. The aggregate weight of the 19 commodities is 93.44% in the SP-GSCI and 78.21% in the DJ-UBSCI in 2010, so they are very representative. As shown in Table I, the SP-GSCI is heavily weighted on the energy sector, with a total weight of 69.25% and a crude oil weight of 50.05%. The weights in the DJ-UBSCI are more evenly dispersed, and the total energy weight is only 33%.

[Insert Table I]

Commodity index investments give investors exposure to commodity prices. There is both academic and industrial research that suggests that even when a commodity index may be a poor stand-alone investment, it is still desirable because of the hedging against inflation and the diversification benefit added to the investors' total portfolio. Gorton and Rouwenhorst (2006) find that over the period between July 1959 and March 2004, the returns of investing in commodity futures were negatively correlated with equity and bond returns, but positively correlated with inflation. Based on the examination of asset class data from 1970 to 2004, Idzorek (2006) shows that by adding commodity indices into the portfolio, the average improvement in historical return at each risk level (standard deviation range of approximately 2.4% to 19.8%) was approximately 1.33%, with a maximum of 1.88%. However, a recent study by Tang and Xiong (2010) find that with the boom of commodity index investments, commodity prices have been increasingly exposed to market-wide shocks and shocks to other commodities, such as oil. Therefore, it is not clear whether or not the diversification benefit of commodity index investment is sustainable in the future.

A. The Goldman Roll

Since futures contracts have expiration dates, to maintain the long exposure to commodity prices, commodity indices need to roll the positions forward, i.e., by closing the long positions in the maturing contracts and initiating new long positions in contracts that have later maturity dates. Table

the futures contracts listed on LME is very different from that in US. The maturities of these futures contracts range from one day to 3 months consecutively. It is not clear from the index documentations which contracts these indices choose and how they roll the contracts forward.

[7]The weights are taken in 2010. The index committee may revise the weights depending on various factors each year, so the weights in previous years can be different from the current weights, but the differences are usually small.

I shows the rolling scheme of the SP-GSCI by listing the maturities of the futures contracts held by the index on the first business day of each calendar month. If the index holds different contracts at the beginnings of two consecutive months, it means that the index rolls futures forward in the first month. For example, the SP-GSCI holds the March and May wheat contracts at the beginning of February and March respectively, so the index rolls the wheat futures forward in February by closing the March contracts and initiating the May contacts. Since the liquidity of contracts drops very quickly as the maturity increases, commodity indices usually hold contracts with short maturities. Different commodities have different rolling frequencies. Agricultural and precious metal commodities are typically rolled forward 4 to 5 times a year. The livestock commodities are rolled forward a bit more frequently, 6 to 8 times a year. The SP-GSCI rolls the energy commodities every month. The rolling scheme of the DJ-UBSCI is the same for most commodities except energy commodities, which are rolled every two months.

In the rolling month, both the SP-GSCI and DJ-UBSCI have a rolling period of 5 business days. The SP-GSCI starts on the fifth business day of the month, and ends on the ninth business day, while the DJ-UBSCI rolls from the sixth business day to the tenth business day, so the rolling periods of the two indices greatly overlap. Many other indices and ETFs also roll in this period, like the former Lehman Brothers Commodity Index and the largest crude oil ETF: United States Oil Fund (USO). On each day of the rolling period, both indices roll forward 20% of the positions for commodities that need to be rolled. Since the DJ-UBSCI's rolling rules are very similar to the SP-GSCI which is much more popular, in the following empirical analysis, I will focus on the rolling activity of the SP-GSCI, which is called the Goldman roll by practitioners.

The total excess return of investing in futures contracts consists of spot return and roll yield. Spot return captures the price change of the futures contracts that investors hold. Roll yield (also called roll return) captures the slope of futures curve when investors roll futures forward. From now on, the contracts held by the SP-GSCI will be referred to as the maturing contracts, and the contracts that the SP-GSCI rolls into will be called the deferred contracts. Suppose the price of the maturing contract is F_{t,T_1} at time t with maturity T_1, and F_{t,T_2} is the price of the deferred contract with maturity T_2, where $T_2 > T_1$. The roll yield is defined as

$$Roll\ Yield = ln(F_{t,T_1}) - ln(F_{t,T_2}) \tag{1}$$

When the maturing contract is more expensive $F_{t,T_1} > F_{t,T_2}$, the term structure is usually called in *backwardation* and the roll yield is positive. When the maturing contract is at a discount $F_{t,T_1} < F_{t,T_2}$, the term structure is called in *contango* and the roll yield is negative.

Historically, the roll yield is an important component of the total excess return. Anson (1998) shows that the roll yield provided most of commodity investments' total excess return in the period between 1985 and 1997, and in the case of the SP-GSCI, the average annual roll yield was 6.11% while the average spot return was -0.08%. Feldman and Till (2006) find that from 1983 to 2004, whether a commodity was in structural backwardation or not largely determined its returns, and roll yield has been the dominant driver of commodity futures returns.

II. Empirical Analysis

The daily prices for individual commodity's futures contracts are obtained from the Commodity Research Bureau (CRB) and the full sample period is from January 2, 1980 to March 31, 2010[8]. In the following analysis, the year 2000 is often set as a cutoff point, since commodity index investment was nonexistent or very small (less than $6 billion) before 2000. As shown later, the exact choice of the cutoff point is not important and does not change the results. To facilitate the analysis, I form a control group using 18 commodities not included in the SP-GSCI with futures trading on US exchanges since 2005 or earlier. These commodities will be referred to as *out-of-index commodities*. I apply a similar rolling scheme as the SP-GSCI by matching the sector and maturity structures of futures markets. The rolling periods of these commodities are exactly the same as the SP-GSCI. Table II lists the commodities in this control group[9] and the rolling scheme.

[8]I exclude the sample before 1980 due to the following considerations. First, there could be some potential structural changes in commodity futures markets, so the data further back may not be so relevant. Second, the SP-GSCI is heavily weighted on energy sector, and the first energy commodity futures (heating oil) started trading at the end of 1979. Third, I check the empirical analysis using all available data and the results are very similar. The results using whole history are available upon request.

[9]The soybean oil is actually included in the DJ-UBSCI and some smaller indices, but the weight is very low. The orange juice is also included in some smaller indices. The copper here is traded on NYMEX, so it is not the

Many commodities in the control group are closely related to some index commodities.

[Insert Table II]

A. Preliminary Evidence of Price Impact

Given the massive size of investment tied to the SP-GSCI, when it rolls futures forward, the large shorting demand of the maturing contract (being rolled from) could potentially push its price down, while the large longing demand of the deferred contract (being rolled into) could push its price up. Together, the resulting price impact would cause the roll yield to drop in the rolling period. In the following analysis, I will provide some preliminary and visual evidence based on this intuition to show the existence of the price impact.

First, a 15-business-day window is constructed to examine the change of roll yields, with the last 5 days being the rolling dates of the SP-GSCI. This window is labeled "rolling window". Days after SP-GSCI's rolling period are not included here, because for energy commodities, after the SP-GSCI unwinds the maturing contracts, these contracts typically have less than a week before the last trading days. Previous empirical studies usually exclude such contracts because of the liquidity concerns. The full sample is divided into two sub-samples: 1980-1999 and 2000-2010. Figure 2 shows the average roll yields (in percentage) of four representative index commodities (crude oil WTI, heating oil, gasoline RBOB and live cattle) over the rolling window in the two periods.

[Insert Figure 2]

The plots in Figure 2 reveal some interesting facts. First, before 2000, the average roll yields were positive on every day for all 4 commodities. It is consistent with the findings of Litzenberger and Rabinowitz (1995) and Casassus and Collin-Dufresne (2005) that these commodities were often in backwardation. In the period 2000-2010, the average roll yields dropped, especially in the SP-GSCI's rolling period. Second and more interestingly, before 2000, the roll yields showed

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same contract which the SP-GSCI and DJ-UBSCI hold. I put milk and butter in the livestock sector because they are produced by livestock and I can have more than one commodity in livestock sector when I form sector portfolios later.

no clear trend in the window, and the average roll yields in the SP-GSCI's rolling period were not significantly lower than the average roll yields in the first 5 days of the window. The roll yields were also very smooth across the days. However, in the period 2000-2010, we can observe very clear drops of roll yields when entering the SP-GSCI's rolling period, especially for 3 energy commodities. There are decreasing trends for all commodities, and the average roll yields in the SP-GSCI's rolling period are much lower than the average roll yields in the first 5 days, with statistical significance at the 1% level for three energy commodities and at the 5% level for live cattle.

There are also some drops of roll yields from day 6 to day 10, which could be due to the price impact of some other commodity indices that roll futures forward a little earlier than the SP-GSCI. For example, the Reuters/Jefferies-CRB Index (CRB) rolls futures forward between the 1st and 4th business days of the rolling month (day 7 to day 10), and the Deutsche Bank Liquid Commodity Index (DBLCI) has a rolling period which is between the 2nd and 6th business day (day 8 to day 11). The decrease in roll yields can also be caused by some arbitrageurs who front-run the Goldman roll by just a few days.

Second, I examine an alternative 15-business-day window, with the last day being one day earlier than the first day of the rolling window, so the two windows are consecutive. As shown in Figure 3, there were no clear trends over the window and drops on any particular day for all commodities in both time periods. The average roll yields in the last 5 days of the window were not significantly lower than the average roll yields in the first 5 days. In the case of gasoline and heating oil, the average roll yields in the two periods were very close to each other everyday.

[Insert Figure 3]

Finally, to further confirm that the unique pattern is caused by the price impact of the Goldman roll, I pick four representative out-of-index commodities from the control group and examine the change of roll yields in the rolling window. These four commodities are soybean meal, pork belly, propane and copper, one from each sector. As shown in Figure 4, the results form clear contrasts to the results of index commodities in the rolling window, but are very similar to the results of index commodities in the alternative window. For all 4 commodities in both periods, there were no clear trends and no significant differences between the average roll yields in the first and last 5 days. Also there were no clear drops of roll yields when entering the rolling period for all 4 commodities in the period 2000-2010.

[Insert Figure 4]

In sum, the time-series and cross-sectional evidence above is very supportive of the existence of the price impact due to the Goldman roll. To provide further and more rigorous evidence, I will design two simple trading strategies to capture the price impact in the next section and show how both statistically and economically significant the price impact was.

B. Front-Running the Goldman Roll

The idea is that since the Goldman roll would cause the maturing contracts to be temporarily underpriced and the deferred contracts to be overpriced, we can create long-short positions to capture this price impact. One can either front-run by creating the spread positions before the Goldman roll or back-run by creating opposite positions at the same time as the Goldman roll. Because there is liquidity concern of maturing contracts after the Goldman roll and the front-running offers more flexibility, I will only focus on front-running strategies.

Assuming that the price of the maturing contract (being rolled from) is F_{t,T_1}, and the deferred contract (being rolled into) has price F_{t,T_2}, then the spread

$$SP_t^{T_1,T_2} = F_{t,T_1} - F_{t,T_2} \tag{2}$$

is the amount of gain (or loss) per unit of the commodity when rolling futures forward. It is also the value of a calendar spread position which shorts one unit of the maturing contract, and longs one unit of the deferred contract. This long-short spread position has little exposure to the change in absolute price level, and is ideal to capture the full impact of price pressures exerted by the Goldman roll in both directions.

Without price impact, the spread $SP_t^{T_1,T_2}$ should be roughly the same over a short time period. With price impact, the spread can decrease in the rolling period because the maturing contract's price F_{t,T_1} would be pushed down and the deferred contract's price F_{t,T_2} would be pushed up. The front-running strategy is designed to capture this drop of spread by shorting the maturing contracts and longing the deferred contracts before the SP-GSCI's rolling period. The spread positions are then unwound and exactly offset the SP-GSCI's positions when it roll futures forward[10].

I focus on the rolling window analyzed in the last section[11]. The 15-day window is equally divided into three groups. The formal trading strategies are designed as follows. With **Strategy 1**, in each month, I first identify the commodities that the SP-GSCI will roll forward. For such commodities, calendar spread positions are created on each day in the first group, which runs from 10 to 6 business days before the SP-GSCI's first rolling date. The spread position involves shorting the maturing contracts that the SP-GSCI is currently holding and longing the deferred contracts that it will roll into. In this way, I create the same spread positions as the Goldman roll, except I do it 10 days earlier. The calendar spread positions will be unwound in the SP-GSCI's rolling period. Like the SP-GSCI, I create 20% of the total spread positions each day and also unwind 20% each day.

Strategy 2 follows the same methodology except front-running the Goldman roll by just 5 days. The spread positions are created in the second group of days, which runs from 5 to 1 business day before the first rolling date of the SP-GSCI. Since both strategies are implemented in very short periods, if they earn very high abnormal excess returns, it is very unlikely to be caused by factors other than the price impact of the Goldman roll. There are multiple ways to improve the simple strategies, but the idea here is to show how the most simple and straightforward strategy would perform.

For commodity i, the excess return of Strategy j $(j = 1,2)$, from day t_j when the spread position

[10]One can also create a butterfly spread position to reduce some exposure to the slope of the futures curve. The butterfly spread position will capture the change in the convexity of the curve, and consists of long positions in the deferred contracts and short positions in the maturing contracts and contracts with maturities later than that of the deferred contracts.

[11]From Figure 3, we can see that moving further ahead of the rolling window would not help the performance a lot.

is created to day $t^{'}$ when the position is unwound, is defined as follows

$$r_t^{i,j} = \frac{SP_{t_j}^{i,T_1,T_2} - SP_{t^{'}}^{i,T_1,T_2}}{(F_{t_j,T_1}^i + F_{t_j,T_2}^i)/2} = \frac{(F_{t_j,T_1}^i - F_{t_j,T_2}^i) - (F_{t^{'},T_1}^i - F_{t^{'},T_2}^i)}{(F_{t_j,T_1}^i + F_{t_j,T_2}^i)/2}. \quad (3)$$

This return is an excess return because the collateral earns the interest of risk-free rates. I also assume that both strategies invest the capital in the risk-free asset when they are not front-running the Goldman roll, so if the SP-GSCI rolls commodity i forward in the month, the monthly excess return of investing in commodity i with Strategy j is just the 5-day average of $r_t^{i,j}$, otherwise the monthly excess return is zero.

The 19 commodities are grouped by sector to form equally weighted portfolios (agriculture, energy, livestock and metals), and a total portfolio using all commodities. In each month, the portfolio's return is the average return of the commodities that the SP-GSCI rolls forward in this portfolio during the month. Equation (3) also indicates that the spread position is fully collateralized, so the excess return $r_t^{i,j}$ involves no leverage. In practice, the margin requirement is about 10-15% of the nominal value for creating an outright futures position, and only 2-4% for initiating a calendar spread position, so both strategies can be easily implemented using very high leverage in the real world.

B.1. Performance of the Strategies

Similar to the previous analysis, I divided the full sample period into two sub-periods: 1980-1999 and 2000-2010. Table III reports the summary statistics of the five portfolios' monthly excess returns (in percentage). The difference of performances in the two periods is striking. Let us first discuss Strategy 1.

[Insert Table III]

First, the mean excess returns of all 5 portfolios were very significantly positive in the period 2000-2010, and much larger than the mean excess returns before 2000. In the period 1980-1999, besides the metals portfolio, the mean excess returns ranged from -0.006% (energy) to 0.13%

(agriculture) monthly, while in the period 2000-2010, the mean excess returns increased to a range of 0.31% (total) to 0.42% (livestock) monthly. The mean excess return was relatively small in magnitude for the metals portfolio, but still it increased from -0.028% before 2000 to 0.033% since 2000.

Second, the monthly Sharpe ratios surged to very high levels in the period 2000-2010, ranging from 0.32 (agriculture) to 0.79 (total). In the period 1980-1999, besides the agriculture portfolio, the monthly Sharpe ratios of the other 4 portfolios were typically low or even negative, ranging from -0.14 (metals) to 0.15 (total). The jumps in monthly Sharpe ratios were especially striking for three portfolios: energy portfolio (from -0.007 to 0.64), metals portfolio (from -0.14 to 0.55) and total portfolio (from 0.15 to 0.79).

Third, except for the agriculture portfolio, 4 portfolios' excess returns were positively skewed in the period 2000-2010, with skewness ranging from 0.13 (total) to 2.23 (metals). This makes it more difficult to explain the high Sharpe ratios with risk based theories. In contrast, in the period 1980-1999, the skewness was slightly positive 0.19 for the livestock portfolio, and negative for the other 3 portfolios, ranging from -3.12 (metals) to -0.17 (total).

Finally, in the period 2000-2010, 4 portfolios experienced big drops in the maximum drawdown. The most dramatic ones are energy and metals portfolio, whose maximum drawdowns decreased from 22.4% before 2000 to only 0.94% and from 7.4% to 0.09% respectively.

The results for Strategy 2 are similar, and even stronger in some cases. Besides the agriculture portfolio, the mean excess returns of the other 4 portfolios were not significantly different from zero before 2000, ranging from -0.013% (metals) to 0.027% (energy), but they became very positive and highly significant in the period 2000-2010, ranging from 0.019% (metals) to 0.22% (energy). The monthly Sharpe ratios of these 4 portfolios ranged from -0.11 (metals) to 0.06 (total) before 2000, and increased to the range of 0.21 (livestock) to 0.52 (metals) since 2000. The skewness of excess return also increased a lot for the energy, livestock and metals portfolios, among which the energy portfolio experienced a jump from 0.09 before 2000 to 2.45 since 2000.

Panel A of Table IV reports the summary statistics of the portfolios' annualized excess returns in the period 2000-2010. The annual Sharpe ratios ranged from 1.09 (agriculture) to 2.75 (total) with Strategy 1, and from 0.46 (agriculture) to 1.78 (metals) with Strategy 2. So far the capital is assumed to be invested in the risk-free assets when not utilized for front-running. However, a large hedge fund could use the capital to invest in other assets and trading strategies, so the fund manager may only care about the performance in the period when the capital is actually used. The excess returns with Strategy 1 were actually 10-day returns and should be annualized by multiplying by a factor of 252/10. Similarly, the excess returns with Strategy 2 were 5-day returns and should be annualized by a factor of 252/5. As reported in Panel B of Table IV, the annualized Sharpe ratios now are much higher, ranging from 2.0 (agriculture) to 3.99 (total) with Strategy 1 and from 1.16 (agriculture) to 4.39 (metals) with Strategy 2. Besides the metals portfolio, the means of *unlevered* annual excess returns ranged from 7.8% (total) to 10.47% (livestock) with Strategy 1, and ranged from 5.16% (agriculture) to 10.8% (energy) with Strategy 2. Therefore, the strategies' performances are much better from the perspective of a money manager with multiple investing opportunities.

[Insert Table IV]

The CRB data set does not have data on the bid-ask-spreads, so I can not incorporate transaction costs into the evaluation of the strategies. However, since the index commodities have the most liquid markets among all commodities, and the contracts involved in the Goldman roll are also the most liquid contracts in each market, the transaction costs are quite low. The typical bid-ask-spread is only a few bps (basis points) of the futures price. For crude oil (WTI), the bid-ask-spread is often just 1 bp. In addition, since the trading volumes tend to increase a lot in the SP-GSCI's rolling period, the bid-ask-spread can be even lower when the strategies unwind the spread positions. Therefore, the strategies should still be very profitable even after taking into account the transaction costs, especially in the most liquid energy sector.

Now let us focus on Strategy 1 and take a closer look at the excess returns year by year. Figure 5 shows each year the average monthly excess returns (in percentage) of the 4 sector portfolios. The energy and livestock portfolios actually had mostly positive excess returns as early as 1992, right after the launch of the SP-GSCI. For the metals portfolio, the average excess returns were mostly negative before 2000, and then stayed positive every year from 2000. The agriculture portfolio is quite different from the other 3 portfolios. The average excess returns have been mostly positive in the whole sample period, and there was a cyclical pattern before 2003. However, since 2003, the cyclical pattern disappeared and the average excess returns have stayed positive every year. The plots indicate that the exact choice of the cutoff year is not very important, and the results can be even better if the cutoff year is moved a few years earlier.

[Insert Figure 5]

As a comparison, the same trading strategies are applied to the control group with the 18 out-of-index commodities. Similarly, four equally weighted sector portfolios and one total portfolio are formed. Table V reports the summary statistics of these 5 portfolios' monthly excess returns in the same two periods: 1980-1999 and 2000-2010. The results form a very clear contrast to the results in Table III. With both strategies in both periods, most of the 5 portfolios' mean excess returns were not significantly different from 0, or even significantly negative in some cases. The monthly Sharpe ratios were all either negative or close to zero, with a maximum of 0.09 obtained by the energy portfolio with Strategy 1 before 2000. What is more, with Strategy 1, except for the livestock portfolio, the mean excess returns and Sharpe ratios actually dropped in the period 2000-2010 for 4 portfolios. With Strategy 2, there were also 4 portfolios whose mean excess returns and Sharpe ratios decreased in the period 2000-2010.

[Insert Table V]

To further confirm the results, I perform a panel regression which is specified as follows

$$Ret^{i,t} = \alpha + \beta_1 I^{i}_{IndexCom} + \beta_2 I^{i,t}_{inIndex} + Controls + u_{i,t}, \tag{4}$$

where the dependent variable $Ret^{i,t}$ is Strategy's average excess return in the trading period of commodity i in year t and $u_{i,t}$ is the random error. $I^{i}_{IndexCom}$ is an indicator variable, which is equal to 1 if commodity i is an index commodity and 0 if it is an out-of-index commodity. $I^{i,t}_{inIndex}$ is also an indicate variable, which is equal to 1 if commodity i is actually included in the SP-GSCI in year

t and 0 if otherwise. Since the SP-GSCI was launched at the end of 1991, $I^{i,t}_{inIndex} = 0$ for all index commodities before 1992. Among the 19 index commodities, 14 commodities were included at the launch time. Natural gas was added in 1994. Then SP-GSCI included crude oil (Brent), gasoil and Kansas wheat in 1999, and feeder cattle in 2002.

To control for the macroeconomic demand-and-supply conditions and business cycle, the contemporaneous real GDP growth and inflation are included in the regressions. I also include a control variable that is specific to each commodity in each year. This variable is the average roll yield of commodity i in year t. This control variable summarizes the commodity-specific demand-and-supply condition and the average term structure of the futures market. All control variables are demeaned.

The coefficients of interests are α, $\beta_1$and β_2. α is the average of $Ret^{i,t}$ for out-of-index commodities. For index commodities, $\alpha + \beta_1$ is the average of $Ret^{i,t}$ before they were included in the SP-GSCI (or the launch of the SP-GSCI), while $\alpha + \beta_1 + \beta_2$ is the average of $Ret^{i,t}$ after the inclusions. The expected values of α and $\beta_1$are: $\alpha = 0$ and $\beta_1 = 0$, which means that without index investment, the strategy's excess return is 0. If the Goldman roll had price impact, we would expect $\beta_2 > 0$. As reported in Column 1 and 3 of Table VI, the coefficients α and β_1 are not statistically different from 0 for both strategies. After inclusion in the SP-GSCI, Strategy 1 yielded an average excess return of 0.35% in the trading period of 10 days, while Strategy 2 has an average excess return of 0.24% in the 5-day trading period. Both are statistically significant at the 1% level. Column 2 and 4 of Table VI indicates that the results are robust if we only consider index commodities ($I^{i}_{IndexCom} = 1$).

[Insert Table VI]

For the control variables, GDP growth and inflation were both positively correlated with the dependent variable and statistically significant. The commodity-specific control variable–average roll yield of commodity i in year t–is insignificant, which means that the strategies' excess returns are not related the slope of the futures curves.

In sum, the results above indicate that the price impact of the Goldman roll is both statistically and economically significant. The Goldman roll effectively created a large market anomaly and a great trading opportunity for arbitragers.

C. Limits to Arbitrage

All information about the Goldman roll is publicly available. Compared to equity and bond markets, futures markets have much fewer barriers for arbitrage. There is no short-sell constraints, and high leverage can be easily obtained through low margin requirement. The transaction cost is also very low, and the trading strategies are very easy to implement. Therefore, if the market is well arbitraged, we should not expect to see such great performance of front-running the Goldman roll since it would be quickly arbitraged away. The fact that the strategies worked so well in the last decade suggests that there are some limits to arbitrage. The performance of front-running is largely determined by two opposite forces. The positive one is the size of index investment, while the negative one is the size of arbitrage capital utilized to take advantage of the price impact.

From 1986, the CFTC started to publish weekly Commitment of Traders (COT) reports, which includes the aggregate number of spread positions taken by ”Noncommercial” traders. These traders are mainly money managers and labeled speculators in the literature. In order to capture the price impact, the arbitrageurs have to create spread positions, so the number of spread positions held by speculators serves as a good approximation, although the positions are aggregated and the nature of these spread positions can not be exactly identified. Figure 6 shows the average spread positions taken by speculators each year and also their ratios relative to total open interests in the markets of 9 index commodities[12]. For most commodities, there was very few spread positions and also little growth until 2003, especially in energy and livestock sectors, which front-running strategies yielded the best performances. However, the positions started to growth dramatically from 2004 and reached peaks in 2008 for many commodities. The plots suggest that very few arbitrage capital was used to exploit the price impact before 2004, and then as the arbitrageurs became more aware of this trading opportunity, more capital is utilized to exploit this market anomaly. This is consistent with the theory of Duffie (2010) that arbitrage capital can be slow-moving due

[12]Due to limit of space and the large number of commodities, I only report these 9 commodities. The plots for other 8 commodities have similar pattern, and are available upon request.

to arbitrageurs' inattention to a particular market and anomaly. Before 2004, commodity was not a popular asset class and commodity index investment was rarely known among the investment communities.

[Insert Figure 6]

As shown in Figure 5, the 4 sector portfolios enjoyed the best gains in the period 2003-2005, when commodity index investment started the most dramatic growth and there were still not many arbitrageurs. During the three years, the average of unlevered annual excess return was 8.09% for the energy portfolio, 7.18% for the livestock portfolio, 5.62% for the agriculture portfolio and 0.28% for the metals portfolio. However, the performance of the 4 portfolios has been declining since 2006, and the average excess returns dropped to levels close to 0. The livestock portfolio even experienced negative average excess returns since 2008, which suggests a possibility of over-exploiting by arbitrageurs.

The increasing arbitrage capital is an important reason, but another cause is that many investors may have moved their assets away from these commodity index. When the commodity prices collapsed in the middle of 2008, commodity index investment reduced a lot. The data from CFTC's supplement reports shows that the total long positions held by index investors dropped 30-50% from their peaks for many agriculture and livestock commodities in 2008. During this period, many front-running portfolios also experienced their maximum drawdowns. Also, a new generation of commodity indices emerged since 2006 with more intelligent rolling methodologies. Many investments moved from the old generation to the new generation. Instead of just focusing on contracts with short maturities, new commodity indices search the full term structure, and choose maturities as far as one year ahead. The exact maturity choice usually depends on the term structure of the current market. If the term structure is in contango, they roll into contracts with long maturities to reduce the frequency of rolling and thus the roll cost. If the term structure is in backwardation, they roll into the contracts with close maturities to take advantage of the positive roll yields.

This is consistent with the classic limits to arbitrage theory by Shleifer and Vishny (1997). The arbitrage profit is lower when there is a reduction in size of index investment and an increase in the amount of arbitrage capital in the futures markets. The performance of front-running the Goldman roll is determined by the net result of two opposite forces. To confirm this correlation, I run the following panel regressions for index commodities:

$$Ret^{i,t} = \alpha + \beta_2 I^{i,t}_{inIndex} + \beta_3 I^{i,t}_{inIndex} \times NetRatio^{i,t} + Controls + u_{i,t}. \tag{5}$$

where the dependent variable $Ret^{i,t}$ is Strategy's average excess return in the trading period of commodity i in year t and $I^{i,t}_{inIndex}$ is the indicator variable specified in the last section, which is equal to 1 if commodity i is actually included in the SP-GSCI in year t and 0 if otherwise. $NetRatio^{i,t} = IndexRatio^{i,t} - SpreadRatio^{i,t}$ measures net result of the two forces, where $IndexRatio^{i,t}$ is the average ratio of index investment in commodity i relative to the value of its total open interest and $SpreadRatio^{i,t}$ is the average ratio of spread position held by speculators relative to total open interest.

The data on investment tied to the SP-GSCI and DJ-UBSCI are not publicly available. An annual series of estimated investment tied to the two indices is constructed by collecting data from Masters and White (2008) and the CFTC's reports of index investment[13]. For each index, total value of investment tied to this index is then allocated to individual commodity according to its weighting scheme each year. For individual commodity, the total value of index investment is equal to sum of investment from the two indices.

As reported in Column 1 and 3 of Table VII, the coefficient β_3 is statistically positive for both strategies, especially for Strategy 1, whose average excess return increases by 0.96 bps with 1% increase in the net ratio. Column 2 and 4 of Table VII shows that the results are robust if we only consider index commodities after they were included in the SP-GSCI.

[Insert Table VII]

[13]Masters and White (2008) use sources of Bloomberg, Goldman Sachs and CFTC reports and construct an annual series of estimated investment tied to the two indices from 1991 to 2008 (first 2 quarters). In addition, they estimate that the market share was about 63% for the SP-GSCI and 32% for the DJ-UBSCI in 2008. Starting from fourth quarter of 2007, the CFTC started to publish quarterly reports on the value of total commodity index investment. Only the values of total long positions in the reports are used, and the quarterly data is converted into annual data by using averaging four quarters in one calendar year. Using the estimated market share, I construct the values of investment tied to the SP-GSCI and DJ-UBSCI in 2008 and 2009.

To conclude, the exercise provides empirical evidence that a market anomaly can exist and persist due to slow-moving arbitrage capital. As more people become aware of the price impact, more arbitragers will exploit it and index investors will also move their investments into better designed commodity indices, which cause the anomaly to disappear.

D. Cost of the Price Impact

It has been very profitable to exploit the price impact of the Goldman roll, but from the perspective of index investors, how costly was the price impact? In this section, I will estimate the cost of the price impact by comparing two excess return indices. Since the SP-GSCI was launched at the end of 1991, I consider the period starting from 1992 for the estimation.

On January 2 1992, $100 dollars were assumed to be invested in futures contracts of the 19 index commodities. The investment that each commodity receives from the $100 is proportional to its SP-GSCI weight in 2010. To focus on the cost of the price impact, there is no re-balancing and the choice of futures contracts to hold is exactly the same as the SP-GSCI. I construct two indices with different rolling periods. One index rolls the futures forward in the SP-GSCI's rolling period, and is labeled ”SP-GSCI Roll” index, so this index rolls exactly the same as the Goldman roll. The other index rolls just 10 business days earlier, in the first 5 days of the 15-day rolling window we discussed previously, and is labeled ”Earlier Roll” index. The interest earned on collateral is not considered, so the indices are excess return indices.

As shown in Panel A of Figure 7, the values of the two indices closely tracked each other before 2000, and then started to deviate far away. Although the two indices still shared the same pattern in the period 2000-2010 due to the same exposure to the spot returns, the ”Earlier Roll” index outperformed the ”SP-GSCI Roll” index because its roll yields were higher. When commodity prices reached heights in mid-2008, the ”SP-GSCI Roll” index reached a peak value $725, while the ”Earlier Roll” index reached $1099, with difference of $374.

[Insert Figure 7]

As a comparison, I also picked from the control group 12 out-of-index commodities that have data back to 1992 and until 2009. Since there are no reference weights, equal weight is applied to each commodity. The same two rolling rules are applied to form the same two indices: ”SP-GSCI Roll” and ”Earlier Roll”. As shown in Panel B of Figure 7, there is no detectable difference between the values of two indices in the whole period 1992-2009. The maximum difference between the two indices was only about $6.

Table VIII reports the summary statistics of the two indices' annualized excess returns. The full period is divided into two sub-periods: 1992-1999 and 2000-2009. For the 19 index commodities, the excess returns of the two indices had almost the same standard deviations and skewness in both periods, but the means are quite different. The ”SP-GSCI Roll” index yielded an annual excess return of 2.31% before 2000 and 7.93% since 2000, while the ”Earlier Roll” index outperformed it annually by 1.66% and 3.59% respectively. Therefore, the Sharpe ratio of the ”Earlier Roll” index was 82% higher in the period 1992-1999 and 48% higher in the period 2000-2009. In addition, the difference in excess returns had a positive skewness 0.43 before 2000, and 0.79 from 2000, which indicates the arbitrage opportunity induced by the price impact. It is also statistically significant that the mean difference in excess returns in the period 2000-2009 is larger than the mean difference in the period 1992-1999, which suggests that when index investment grew larger, index investors endured a higher cost of the price impact.

[Insert Table VIII]

In a clear contrast, for the 12 out-of-index commodities, all the summary statistics of the two indices are roughly the same in both periods. Although the ”Earlier Roll” index was still slightly better, the out-performance was very small, only about 0.25%, and the difference of excess returns were not always positively skewed.

In order to estimate the cost of the price impact in absolute amount, I assume all index investments are tied to the ”SP-GSCI Roll” index. Each year, the cost due to the price impact is estimated by the size of index investment multiplied by the average difference of excess returns between the ”SP-GSCI Roll” index and ”Earlier Roll” index in this year. As shown in Figure 8, as the index investment grew, the cost also grew fast. From 2004, investing in the ”SP-GSCI Roll” index lost over $2 billion every year to the ”Earlier Roll” index, and in 2009, the loss reached a maximum of $8.4 billion.

[Insert Figure 8]

In sum, because the massive shorting and longing of futures contracts exerts very high price pressure in the rolling period, the resulting price impact has been very costly to index investors in terms of both forgone excess return and absolute amount of loss.

III. Conclusion

Since index funds have very low management fees, investors usually perceive index investment as an inexpensive way to gain broad market exposure. While it seems to be true for the equity index funds, this paper shows that index investment can be very expensive in the commodity markets due to the large price impact of index investors' mechanical rolling forward of futures contracts. Equity index funds invest directly in the underlying assets, so the fund managers rarely need to change positions besides the inflow and outflow of funds. While there are some documented inefficiencies in equity investment, like the inclusion and exclusion effects, the resulted costs are quite small, because the inefficiencies only happen at very low frequency and changes are very small relative to the total positions of the investments. Commodity index investment is very different, because investors take long positions in futures contracts. Since futures contracts have expiration dates, commodity index investors have to roll their entire positions forward at monthly frequency, which resulted a much higher cost due to the large price impact of this rolling activity.

Concern about price impact motivated some second-generation commodity indices to have longer rolling periods so that the price pressure on each rolling date is very small. Some new indices now roll futures forward at daily frequency. However, it seems that many other new indices still do not recognize the possible price impact, because they still have very short rolling periods, and the new rolling methodologies are mainly designed to reduce the roll cost in the current contango markets. As discussed, these indices tend to roll into contracts with long maturities, but these contracts are not as liquid as the contracts with short maturities, so the price impact of the rolling activity could be quite large even though the investment tied to these indices is small. As these indices get more popular, the price impact and the resulted cost can be even larger.

This extends to a more general question of security design. Commodity indices are very different from the traditional securities, because investing in them requires continuous management due to the special rolling requirement. Therefore, the designer has to think about the possible negative effects of fixed management actions when the assets under management grow larger, and whether the designed index will be immune to these effects. Another problem is that as the designer tries to minimize the potential negative effects, the management rules could become very complicated. As the complexity of the index increases, the cost of replicating it and thus the management fee increases, and investors may also feel more difficult to understand and analyze the index. There is a balance between the potential benefits and costs associated with the complexity of securities. These problems also apply to the design of exchange-traded funds (ETFs), which are becoming more and more popular among investors.

Although the market anomaly created by the Goldman roll can be arbitraged away by enough arbitrageurs, the impact of index investment will not disappear. As more and more arbitrageurs try to front-run the Goldman roll and also each other, they can spread the price impact out to other dates and also other maturities. This can have a profound effect on the term structure of commodity futures markets, and may potentially be one of the reasons why the term structures of many index commodities have moved from backwardation towards contango in recent years, which can have important implications for production and consumption of these commodities. Further research can investigate this hypothesis and look at the impact of index investment on commodity term structure, supply and demand.

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Table I - Commodity Futures and Their Weights in the SP-GSCI and DJ-UBSCI

Table I: This table lists the futures contracts of 19 commodities in the SP-GSCI. The first column lists the trading facility of the commodity. The third and fourth column list the weight of the commodity in the SP-GSCI and DJ-UBSCI. These weights are taken in 2010. The fifth column list the starting month of futures market for each commodity. The last 12 columns show the rolling scheme of the SP-GSCI by listing the maturities of the futures contracts held by the SP-GSCI at the beginning of each calender month.

Trading	Commodity	SP-GSCI	DJ-UBSCI	Futures	Maturity of contracts at Month Begin											
Facility	(Contracts)	Weights	Weights	Since	1	2	3	4	5	6	7	8	9	10	11	12
Agriculture (8 Commodities)																
ICE	Cocoa	0.36%	0.0%	1964.12	H	H	K	K	N	N	U	U	Z	Z	Z	H
ICE	Coffee "C"	0.78%	2.56%	1972.08	H	H	K	K	N	N	U	U	Z	Z	Z	H
CBOT	Corn	3.99%	7.09%	1964.12	H	H	K	K	N	N	U	U	Z	Z	Z	H
ICE	Cotton #2	0.96%	2.00%	1964.12	H	H	K	K	N	N	Z	Z	Z	Z	Z	H
CBOT	Soybean	2.77%	7.91%	1964.12	H	H	K	K	N	N	X	X	X	X	F	F
ICE	Sugar #11	1.92%	2.89%	1964.12	H	H	K	K	N	N	V	V	V	H	H	H
KBOT	Wheat (Kansas)	0.86%	0.0%	1970.01	H	H	K	K	N	N	U	U	Z	Z	Z	H
CBOT	Wheat	4.05%	4.70%	1964.12	H	H	K	K	N	N	U	U	Z	Z	Z	H
Livestock (3 Commodities)																
CME	Feeder Cattle	0.56%	0.0%	1972.03	H	H	J	K	Q	Q	Q	U	V	X	F	F
CME	Lean Hogs	1.54%	2.10%	1966.02	G	J	J	M	M	N	Q	V	V	Z	Z	G
CME	Live Cattle	3.01%	3.55%	1964.12	G	J	J	M	M	Q	Q	V	V	Z	Z	G
Energy (6 Commodities)																
ICE	Crude Oil (Brent)	13.14%	0.0%	1989.07	H	J	K	M	N	Q	U	V	X	Z	F	G
NYMEX	Crude Oil (WTI)	36.91%	14.34%	1983.03	G	H	J	K	M	N	Q	U	V	X	Z	F
ICE	Gasoil	4.78%	0.0%	1986.06	G	H	J	K	M	N	Q	U	V	X	Z	F
NYMEX	Gasoline (RBOB)	4.56%	3.53%	1984.12	G	H	J	K	M	N	Q	U	V	X	Z	F
NYMEX	Heating Oil #2	4.54%	3.58%	1978.11	G	H	J	K	M	N	Q	U	V	X	Z	F
NYMEX	Natural Gas	5.32%	11.55%	1990.04	G	H	J	K	M	N	Q	U	V	X	Z	F
Metals (2 Commodities)																
NYMEX	Gold	2.86%	9.12%	1974.12	G	J	J	M	M	Q	Q	Z	Z	Z	Z	G
NYMEX	Silver	0.31%	3.29%	1964.12	H	H	K	K	N	N	U	U	Z	Z	Z	H

F: January G: February H: March J: April K: May M: June N: July Q: August U: September V: October X: November Z: December

Table II - Commodities Futures out of the SP-GSCI and their Rolling Scheme

Table II: This table lists the commodities out of the SP-GSCI that I use to form the control group. The first column lists the trading facility and the second column shows the name of commodity. The third column lists the length of futures data. The last 12 columns show the rolling methodology by listing the maturity of contracts held on the first business day of the calender month. The rolling methodology is set similar to the SP-GSCI by matching the sector and maturity structure. The ”Butter” and ”Milk” are categorized as livestocks because they are produced by livestocks and I could have more than just one commodity in this sector.

Trading Facility	Commodity (Contracts)	Futures Data Period	Maturity of contracts at Month Begin											
			1	2	3	4	5	6	7	8	9	10	11	12
Agriculture (8 Commodities)														
CME	Lumber	1969.10–2010.3	H	H	K	K	N	N	U	U	X	X	F	F
CBOT	Oats	1959.7–2010.3	H	H	K	K	N	N	U	U	Z	Z	Z	H
ICE	Orange Juice	1967.2–2010.3	H	H	K	K	N	N	U	U	X	X	F	F
CBOT	Rough Rice	1986.8–2010.3	H	H	K	K	N	N	U	U	X	X	F	F
CBOT	Soybean Meal	1959.7–2010.3	H	H	K	K	N	N	V	V	V	F	F	F
CBOT	Soybean Oil	1959.7–2010.3	H	H	K	K	N	N	V	V	V	F	F	F
ICE	Sugar #14	1985.7–2008.2	H	H	K	K	N	N	U	U	X	X	F	F
MGEX	Wheat, Spring	1970.1–2010.3	H	H	K	K	N	N	U	U	Z	Z	Z	H
Livestock (3 Commodities)														
CME	Butter	1996.9–2010.3	G	H	K	K	N	N	U	U	V	Z	Z	G
CME	Milk, Class III	1996.1–2010.3	G	J	J	M	M	N	U	U	Z	Z	Z	G
CME	Pork Bellies	1966.2–2010.3	G	H	K	K	N	N	Q	G	G	G	G	G
Energy (4 Commodities)														
NYMEX	Coal	2001.7–2010.3	G	H	J	K	M	N	Q	U	V	X	Z	F
NYMEX	Electricity, PJM	2003.4–2010.3	G	H	J	K	M	N	Q	U	V	X	Z	F
CBOT	Ethanol	2005.3–2010.3	G	H	J	K	M	N	Q	U	V	X	Z	F
NYMEX	Propane	1987.8–2009.9	G	H	J	K	M	N	Q	U	V	X	Z	F
Metals (3 Commodities)														
NYMEX	Copper	1959.7–2010.3	G	H	J	K	M	N	Q	U	V	X	Z	F
NYMEX	Palladium	1977.1–2010.3	H	H	M	M	M	U	U	U	Z	Z	Z	H
NYMEX	Platinum	1968.3–2010.3	J	J	J	N	N	N	V	V	V	F	F	F

Table III - Summary Statistics of Monthly Excess Returns with Two Front-running Strategies

Table III: This table reports the summary statistics of two front-running strategies in two time periods. The strategies are designed as follows. In each month, I first identify the commodities that the SP-GSCI will roll forward. With Strategy 1, I create spread positions for these commodities from 10 to 6 business days before the SP-GSCI's first roll date. The spread position involves shorting the contracts held by the SP-GSCI and longing the contracts that it will roll into. The spread positions will be unwound in the SP-GSCI's rolling period. Like the SP-GSCI, I create 20% of the spread positions each day, and also unwind 20% each day. For commodity i, the excess return r_t^i is defined in Equation (3). On other dates, the capital is invested in risk-free assets, so the monthly excess return with commodity i is the 5-day average r_t^i if commodity i is rolled over in the month and 0 otherwise. The commodities are grouped to form four sector portfolios and one total portfolio. In each month, the portfolio return is the average return of the commodities in this portfolio.Strategy 2 follows the same methodology except the spread positions are initiated 5 to 1 business days before the first roll date of the SP-GSCI. The excess returns are monthly and in percentage term. The full sample period is from 1980/01/01 to 2010/03/31.

	Agriculture		Energy		Livestock		Metals		Total	
	1980-1999	2000-2010	1980-1999	2000-2010	1980-1999	2000-2010	1980-1999	2000-2010	1980-1999	2000-2010
Strategy 1										
Mean	0.13	0.23	-0.006	0.37	0.12	0.42	-0.03	0.033	0.06	0.31
T-stat	3.29	3.50	-0.11	7.05	1.96	5.34	-2.17	6.14	2.36	8.81
Std	0.61	0.73	0.81	0.58	0.93	0.86	0.20	0.06	0.41	0.39
Skewness	1.78	-2.61	-0.71	0.88	0.19	0.74	-3.12	2.23	-0.17	0.13
Kurtosis	9.93	35.1	6.69	4.45	3.83	5.55	24.6	12.8	3.32	5.75
Min	-1.84	-5.39	-3.82	-0.88	-2.93	-1.72	-1.66	-0.087	-1.19	-1.22
Max	2.73	3.73	2.66	2.38	3.22	4.32	0.69	0.39	1.06	1.70
Sharpe Ratio	0.21	0.32	-0.007	0.64	0.13	0.48	-0.14	0.55	0.15	0.79
Max Drawdown	2.09	5.39	22.40	0.94	8.73	7.53	7.40	0.09	5.25	1.44
# of obs	240	123	240	123	240	123	240	123	240	123
Strategy 2										
Mean	0.05	0.07	0.027	0.21	0.01	0.13	-0.013	0.019	0.02	0.13
T-stat	2.13	1.47	0.66	4.81	0.25	2.33	-1.65	5.71	0.97	4.53
Std	0.38	0.51	0.64	0.50	0.62	0.61	0.12	0.04	0.31	0.31
Skewness	-1.15	-1.40	0.09	2.45	-0.07	0.12	-3.34	0.76	-0.16	-0.61
Kurtosis	12.9	33.4	7.13	15.8	4.38	3.97	21.2	5.40	4.34	11.0
Min	-1.91	-3.63	-2.44	-0.81	-2.14	-1.69	-0.85	-0.08	-0.94	-1.53
Max	1.54	3.06	2.85	3.37	2.07	2.25	0.3	0.15	1.27	1.35
Sharpe Ratio	0.17	0.16	0.04	0.43	0.02	0.21	-0.12	0.62	0.06	0.41
Max Drawdown	2.87	3.63	15.09	2.61	17.26	5.19	3.40	0.08	9.34	2.05
# of obs	240	123	240	123	240	123	240	123	240	123

Table IV - Summary Statistics of Annualized Excess Returns in the Period 2000-2010

Table IV: This table reports the summary statistics of annualized excess returns in the period 2000-2010. In Panel A, capital is invested in risk-free asset when it is not utilized for the trading strategies, and excess returns are treated as monthly excess returns and annualized by multiplying 12. In Panel B, excess returns are treated as the excess returns in the period when the capital is actually utilized for the trading strategies. With Strategy 1, the excess returns are annualized by multiplying 252/10, and with Strategy 2, the excess returns are annualized by multiplying 252/5. The full sample period is from 1980/01/01 to 2010/03/31.

Panel A: Annualized by Month

	Agriculture	Energy	Livestock	Metals	Total
Strategy 1					
Mean	2.74%	4.43%	4.99%	0.40%	3.71%
Std	2.51%	2.01%	2.99%	0.21%	1.35%
Skewness	−2.61	0.88	0.74	2.23	0.13
Sharpe Ratio	1.09	2.20	1.67	1.92	2.75
Strategy 2					
Mean	0.81%	2.58%	1.53%	0.23%	1.52%
Std	1.76%	1.72%	2.11%	0.13%	1.08%
Skewness	−1.40	2.45	0.12	0.76	−0.61
Sharpe Ratio	0.46	1.50	0.73	1.78	1.41

Panel B: Annualized by Trading Days

	Agriculture	Energy	Livestock	Metals	Total
Strategy 1					
Mean	8.74%	9.30%	10.47%	1.12%	7.80%
Std	4.38%	2.92%	4.34%	0.33%	1.95%
Skewness	−2.69	0.88	0.74	1.82	0.13
Sharpe Ratio	2.00	3.19	2.41	3.36	3.99
Strategy 2					
Mean	5.16%	10.82%	6.43%	1.29%	6.40%
Std	4.44%	3.52%	4.32%	0.29%	2.21%
Skewness	−1.32	2.45	0.12	0.34	−0.61
Sharpe Ratio	1.16	3.08	1.49	4.39	2.90

Table V - Summary Statistics of Monthly Excess Returns with Two Strategies using Out-of-Index Commodities

Table V: This table reports the summary statistics of two front-running strategies in two time periods when applied to the control group of 18 commodities not included in the SP-GSCI. The trading strategies are the same as described in Table III. The excess returns are monthly and in percentage term. The full sample period is from 1980/01/01 to 2010/03/31.

	Agriculture		Energy		Livestock		Metals		Total	
	1980-1999	2000-2010	1980-1999	2000-2010	1980-1999	2000-2010	1980-1999	2000-2010	1980-1999	2000-2010
Strategy 1										
Mean	0.02	-0.04	0.12	-0.31	-0.06	0.05	-0.06	-0.10	-0.013	-0.13
T-stat	0.64	-0.97	1.07	-1.81	-0.49	0.25	-1.55	-3.10	-0.25	-1.57
Std	0.51	0.47	1.34	1.93	1.87	2.07	0.59	0.35	0.83	0.90
Skewness	-0.73	-0.64	0.76	-0.42	1.50	-2.69	-0.84	0.06	1.27	-0.90
Kurtosis	8.17	6.16	11.0	4.42	19.8	16.7	10.9	11.2	13.3	5.63
Min	-2.48	-2.09	-5.46	-7.91	-7.50	-12.8	-2.70	-1.40	-3.57	-4.18
Max	1.70	1.15	6.39	4.66	12.1	4.17	3.34	1.73	5.13	1.80
Sharpe Ratio	0.04	-0.09	0.09	-0.16	-0.03	0.02	-0.10	-0.28	-0.02	-0.14
# of obs	240	123	145	123	240	123	240	123	240	123
Strategy 2										
Mean	0.003	-0.07	0.032	-0.10	-0.004	0.03	-0.035	-0.04	0.006	-0.06
T-stat	0.11	-2.26	0.37	-0.76	-0.05	0.25	-1.32	-2.15	0.15	-0.91
Std	0.39	0.35	1.04	1.52	1.36	1.54	0.41	0.20	0.62	0.71
Skewness	-1.24	-1.04	0.36	-0.26	2.38	-2.14	1.24	2.03	1.94	-0.83
Kurtosis	12.4	9.34	12.2	5.21	24.0	16.1	14.6	19.0	16.6	6.47
Min	-2.54	-1.85	-2.44	-5.97	-5.74	-8.64	-1.94	-0.74	-2.57	-3.10
Max	1.44	1.29	5.32	5.14	9.04	5.77	2.69	1.28	4.32	2.17
Sharpe Ratio	0.01	-0.20	0.03	-0.07	-0.003	0.02	-0.09	-0.19	0.01	-0.08
# of obs	240	123	145	123	240	123	240	123	240	123

Table VI - Regressions on the Trading Strategies' Excess Returns 1

Table VI: This table reports the results from regressions of Strategies' average excess return during the trading days ($Ret^{i,t}$), where i indicates commodity and t indicates year. $I^{i}_{IndexCom}$ is an indicator variable, which equal to 1 if commodity i is an index commodity and 0 otherwise. $I^{i,t}_{inIndex}$ is an indicator variable, which equal to 1 if commodity i is included in the SP-GSCI at year t and 0 otherwise. The control variables include: $RY^{i,t}$, average roll yields of commodity i in year t, $growth^{t}_{GDP}$, real GDP growth in year t, and $Inflation^{t}$, the inflation in year t. All the control variables are demeaned. The sample period is from 1980 to 2009. In each year t, commodities are clustered to account for possible cross-sectional correlation. * denotes significance at the 10% level, ** denotes significance at the 5% level, and *** denotes significance at the 1% level.

	Dependent variable: $Ret^{i,t}$			
	Strategy 1		Strategy 2	
	All	$I^{i}_{IndexCom} = 1$	*All*	$I^{i}_{IndexCom} = 1$
	1	2	3	4
Constant	−0.028	0.011	−0.026	−0.030
	(0.040)	(0.022)	(0.024)	(0.022)
$I^{i}_{IndexCom}$	0.029		−0.016	
	(0.044)		(0.034)	
$I^{i,t}_{inIndex}$	0.35***	0.33***	0.24***	0.22***
	(0.057)	(0.060)	(0.036)	(0.034)
Controls				
$RY^{i,t}$	−0.031	−0.022	−0.008	0.002
	(0.019)	(0.016)	(0.011)	(0.012)
$growth^{t}_{GDP}$	0.034***	0.033**	0.030***	0.035***
	(0.011)	(0.013)	(0.007)	(0.009)
$Inflation^{t}$	0.032***	0.021**	0.019***	0.005
	(0.008)	(0.009)	(0.006)	(0.010)
R^2_{adj}	8.89%	10.25%	7.82%	10.72%
obs	956	537	956	537

Table VII - Regressions on the Trading Strategies' Excess Returns 2

Table VII: This table reports the results from regressions of Strategies' average excess return during the trading days ($Ret^{i,t}$), where i indicates commodity and t indicates year. $I^{i}_{IndexCom}$ and $I^{i,t}_{inIndex}$ are indicator variable defined in Table VI. $NetRatio^{i,t} = IndexRatio^{i,t} - SpreadRatio^{i,t}$ measures the net effect of two opposite forces, where $IndexRatio^{i,t}$ measures the ratio of index investment in commodity i in year t, and is equal to the index investment in commodity i divided by the value of total open interest. $SpreadRatio^{i,t}$ measures the proportion of spread position held by speculators relative to total open interest in the futures market of commodity i in year t. The control variables include: $RY^{i,t}$, average roll yields of commodity i in year t, $growth^{t}_{GDP}$, real GDP growth in year t, and $Inflation^{t}$, the inflation in year t. All the control variables are demeaned. The sample period is from 1986 to 2009. In each year t, commodities are clustered to account for possible cross-sectional correlation. * denotes significance at the 10% level, ** denotes significance at the 5% level, and *** denotes significance at the 1% level.

Dependent variable: $Ret^{i,t}$				
	Strategy 1		Strategy 2	
	$I^{i}_{IndexCom}=1$	$I^{i,t}_{inIndex}=1$	$I^{i}_{IndexCom}=1$	$I^{i,t}_{inIndex}=1$
	1	2	3	4
Constant	0.062^{**}	0.24^{***}	-0.013	0.15^{***}
	(0.029)	(0.05)	(0.026)	(0.039)
$I^{i,t}_{inIndex}$	0.20^{***}		0.18^{***}	
	(0.055)		(0.037)	
$NetRatio^{*}I^{i,t}_{inIndex}$	0.96^{***}	1.04^{***}	0.33^{*}	0.39^{**}
	(0.25)	(0.24)	(0.17)	(0.17)
Controls				
$RY^{i,t}$	0.002	0.002	0.021	0.027
	(0.019)	(0.025)	(0.013)	(0.018)
$growth^{t}_{GDP}$	0.064^{***}	0.078^{**}	0.052^{***}	0.061^{***}
	(0.021)	(0.024)	(0.010)	(0.013)
$Inflation^{t}$	0.012	-0.009	0.002	-0.007
	(0.022)	(0.049)	(0.019)	(0.041)
R^2_{adj}	12.16%	9.26%	11.12%	8.40%
obs	404	287	404	287

Table VIII - Summary Statistics of Two Indices with Different Rolling Periods

Table VIII: This table reports the summary statistics of annualized excess returns of investing in 19 commodities in SP-GSCI index and 12 commodities out of the index with two different rolling periods. SP-GSCI weights are applied to 19 commodities in the index. Out-of-index commodites are equally weighted. ”SP-GSCI Roll” stards for rolling in the SP-GSCI rolling period. ”Earlier Roll” means rolling from 10 to 6 business days before the first roll date of the SP-GSCI. ”DID” stands for ”Difference in Difference”. The returns are continuously compounded returns. The sample period of index commodities is from Jan. 1992 to Dec. 2009. The sample period of out-of-index commodities is from Jan. 1992 to Sep. 2009. ** indicates significance at the 5% level

	1992-1999			2000-2009			
	SP-GSCI Roll	Earlier Roll	Diff.	SP-GSCI Roll	Earlier Roll	Diff.	DID
			19 Index Commodities				
Mean	2.31%	3.97%	1.66%	7.93%	11.52%	3.59%	1.93%**
Sd	21.5%	20.3%	2.20%	34.4%	34.1%	2.36%	
Skewness	0.02	0.05	0.43	−0.3	−0.3	0.79	
Sharpe Ratio	0.11	0.20		0.23	0.34		
			12 Out-of-Index Commodities				
Mean	4.67%	4.90%	0.23%	5.61%	5.87%	0.26%	0.03%
Sd	11.4%	11.4%	1.14%	20.1%	20.2%	1.02%	
Skewness	0.008	−0.001	2.19	−0.2	−0.2	−0.31	
Sharpe Ratio	0.41	0.43		0.28	0.29		

Figure 1: Related Plots of Crude Oil (WTI) Example

This Figure shows the related plots of the crude oil (WTI) example. Panel A shows the term structure of crude oil (WTI) futures on February 7, 2001. Panel B shows the movements of the prices of the March and April contracts from January 24, 2001 to February 13, 2001, a 15-business-day window. Panel C shows the change of spreads between the prices of the March and April contracts over the 15-day window. The spread is equal to the price of March contract minus the price of April contract. Panel D shows the change of roll yields (in percentage) over the 15-day window. The roll yield here is equal to the difference of log prices between the March and April contracts. In Panel B, C and D, the shaded area indicates the SP-GSCI's rolling period.

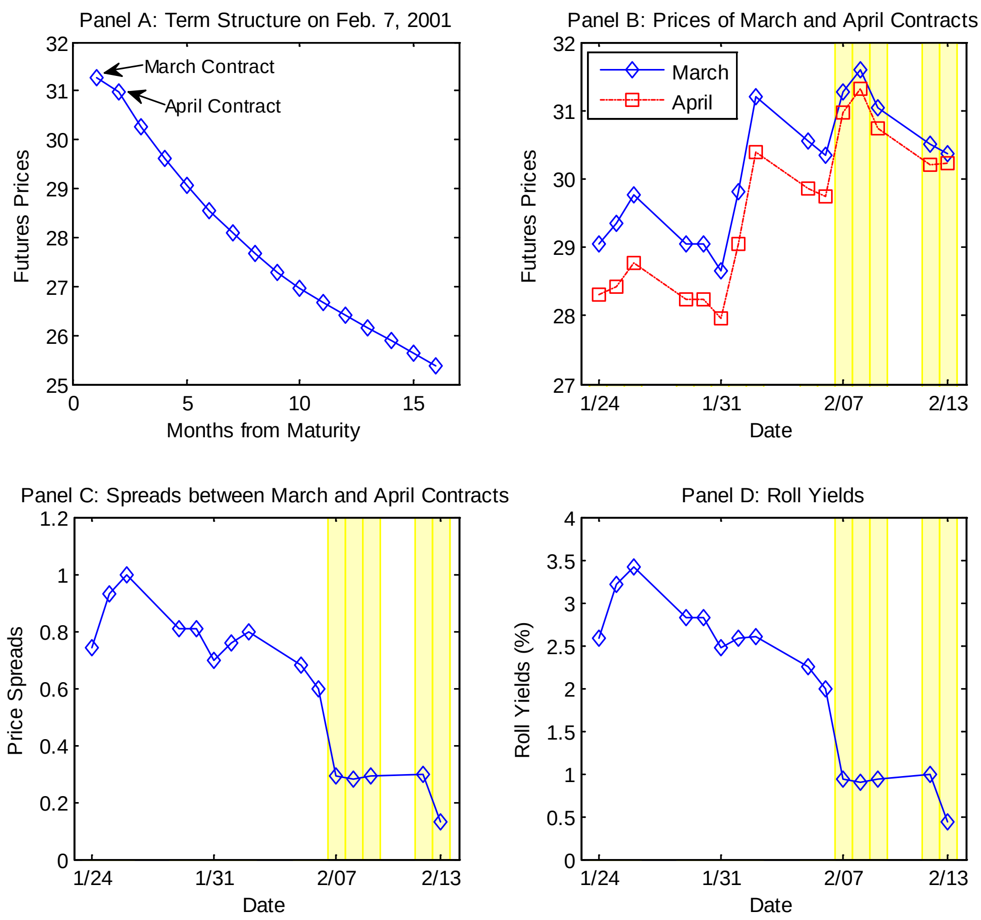


Figure 2: Average Roll Yields of Index Commodities over the 15-day Rolling Window

This Figure shows the average daily roll yields of 4 representative commodities over the 15-day rolling window with the last 5 days being the SP-GSCI's roll dates. The shaded area indicates the SP-GSCI's rolling dates. The roll yields are in percentage units. $RY_{Diff.}^{Period}$ is the difference of average roll yields in the first and last 5 days of the rolling window, which period indicates the specific time period. T-tests are performed to test if the average roll yields in the first 5 days are larger than the average roll yields in the last 5 days. * indicates significance at the 10% level, ** indicates significance at the 5% level, and *** indicates significance at the 1% level. The sample period is from Jan 1980 to Mar 2010 for "Heating Oil" and "Live Cattle". The sample periods of "Crude Oil, WTI" and "Gasoline, RBOB" are from Mar 1983 to Mar 2010 and Dec 1984 to Mar 2010.

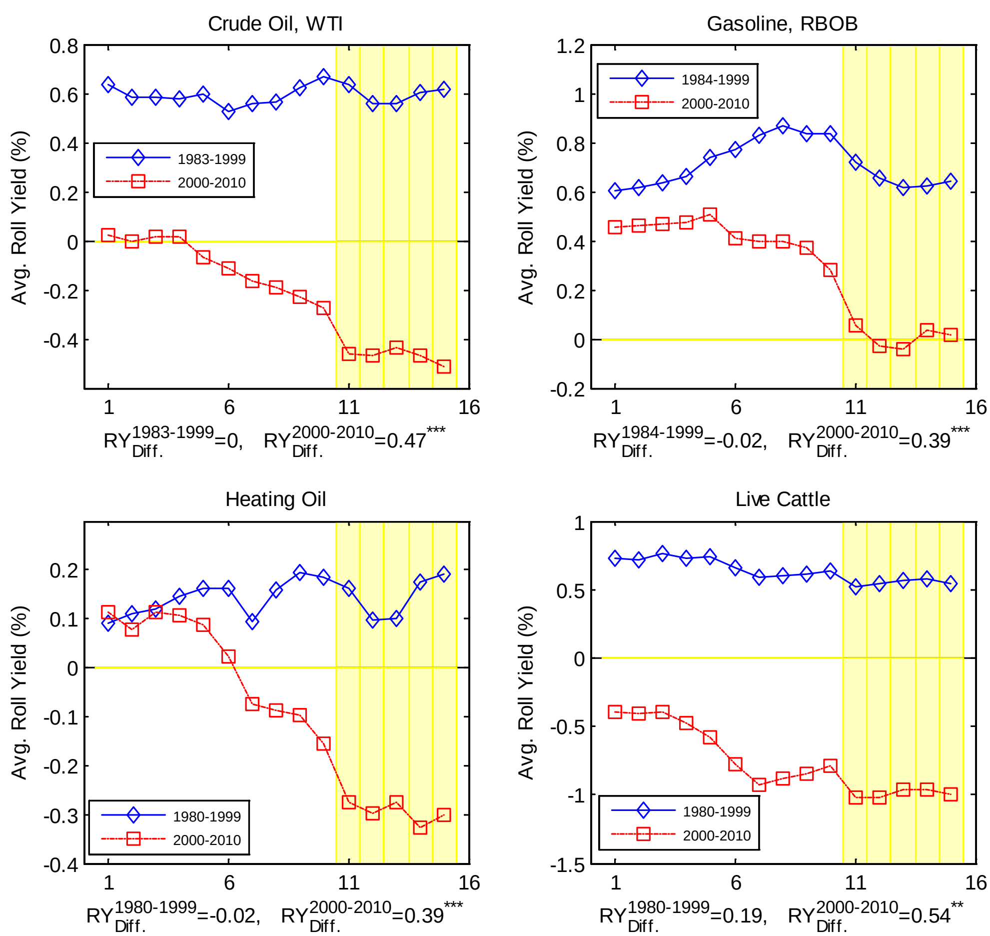


Figure 3: Average Roll Yield of Index Commodities over an Alternative 15-day Window

This Figure shows the average daily roll yields of the 4 representative commodities over an alternative 15-day window with the last day right before the first day of the rolling window. Therefore, this 15-day window ranges from 25 to 11 days before the SP-GSCI's first roll date. The roll yields are in percentage units. $RY_{Diff.}^{Period}$ is the difference of average roll yields in the first and last 5 days of the window, which period indicates the specific time period. T-tests are performed to test if the average roll yields in the first 5 days are larger than the average roll yields in the last 5 days. * indicates significance at the 10% level, ** indicates significance at the 5% level, and *** indicates significance at the 1% level. The sample period is from Jan 1980 to Mar 2010 for "Heating Oil" and "Live Cattle". The sample periods of "Crude Oil, WTI" and "Gasoline, RBOB" are from Mar 1983 to Mar 2010 and Dec 1984 to Mar 2010.

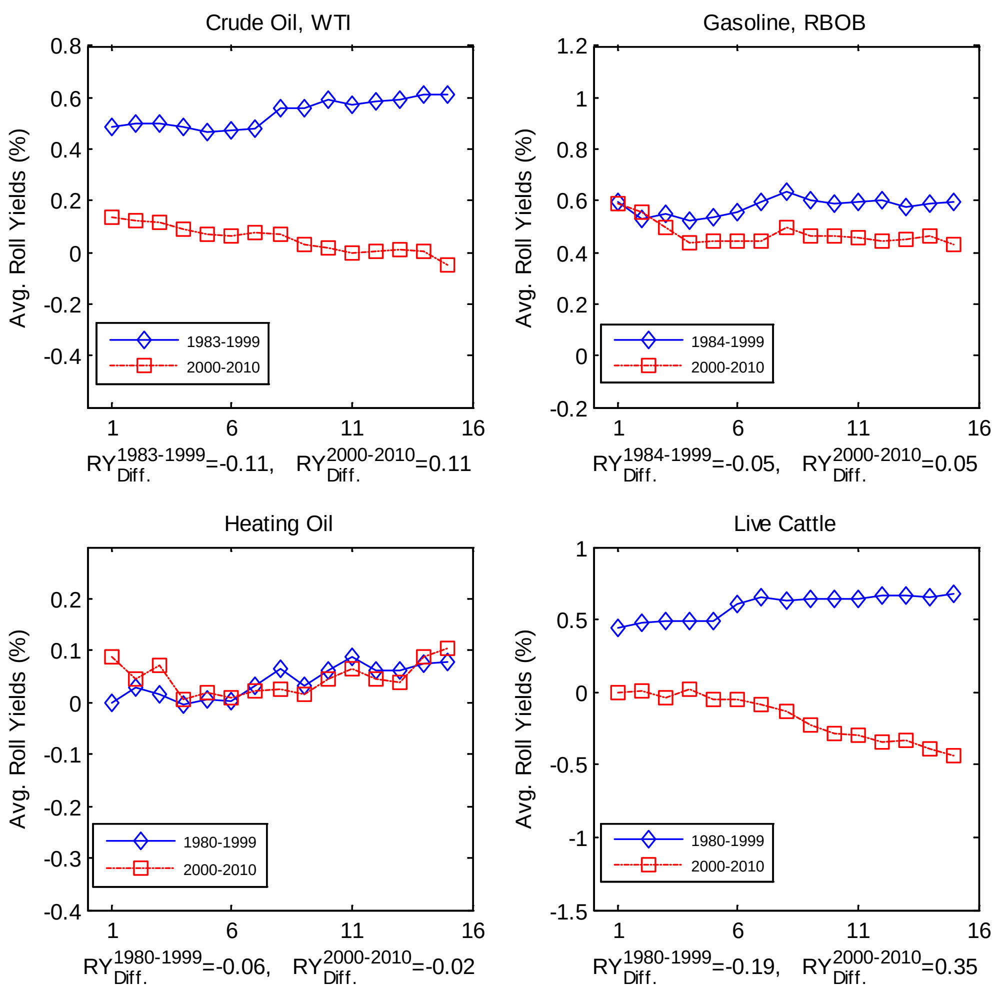


Figure 4: Average Roll Yield of Out-of-Index Commodities over the Rolling Window

This Figure shows the average daily roll yields of 4 representative commodities out of the SP-GSCI over the 15-day rolling window with the last 5 days being the SP-GSCI's roll dates. The shaded area indicates the SP-GSCI's rolling dates. The roll yields are in percentage units. $RY_{Diff.}^{Period}$ is the difference of average roll yields in the first and last 5 days of the rolling window, which period indicates the specific time period. T-tests are performed to test if the average roll yields in the first 5 days are larger than the average roll yields in the last 5 days. * indicates significance at the 10% level, ** indicates significance at the 5% level, and *** indicates significance at the 1% level. The sample period is from Jan 1980 to Mar 2010 for "Soybean Meal", "Pork Belly" and "Copper". The sample period of "Propane" is Aug 1987 to Sep 2009.

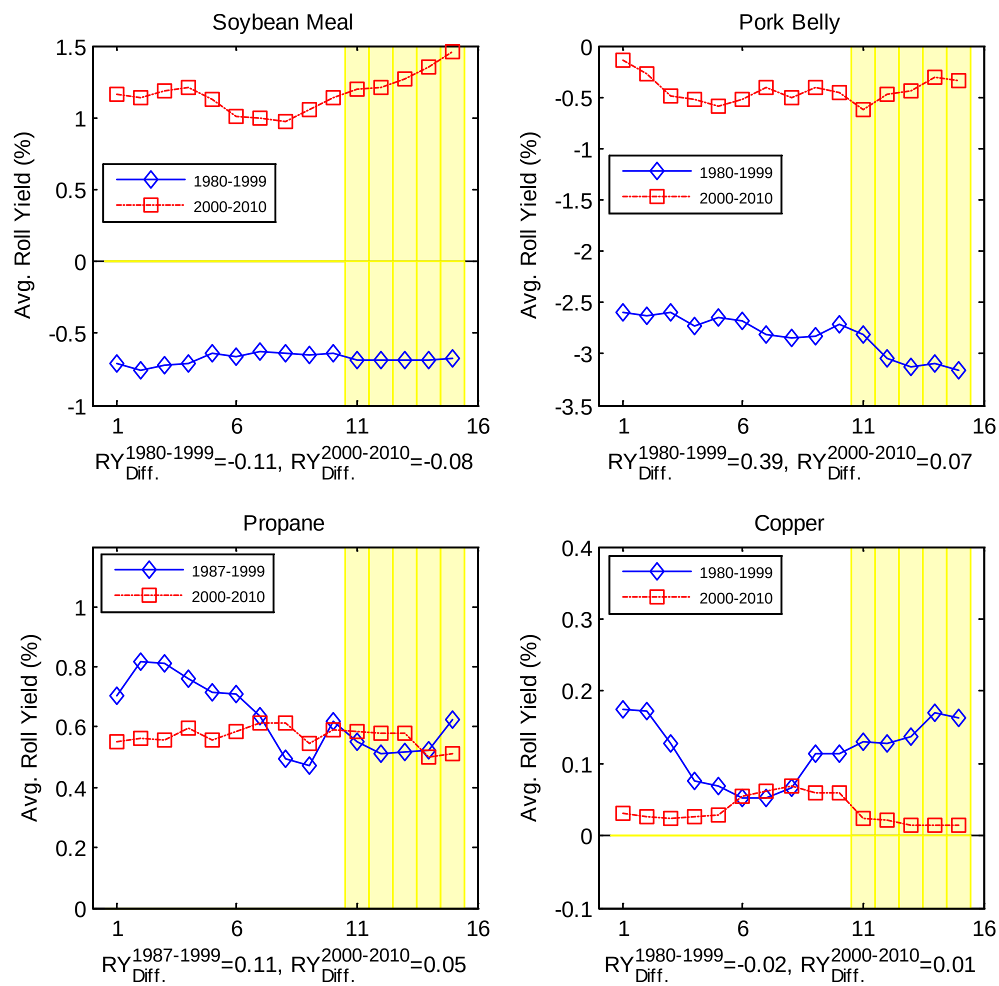


Figure 5: Average Monthly Excess Returns of the Four Sector Portfolios with Strategy 1

This Figure plots the average monthly excess returns each year for the four sector portfolios with Strategy 1. The capital is assumed to invest in risk-free asset when it is not utilized to front-run the Goldman roll. The excess returns are in percentage units. The sample period is from Jan 1980 to Dec 2009.

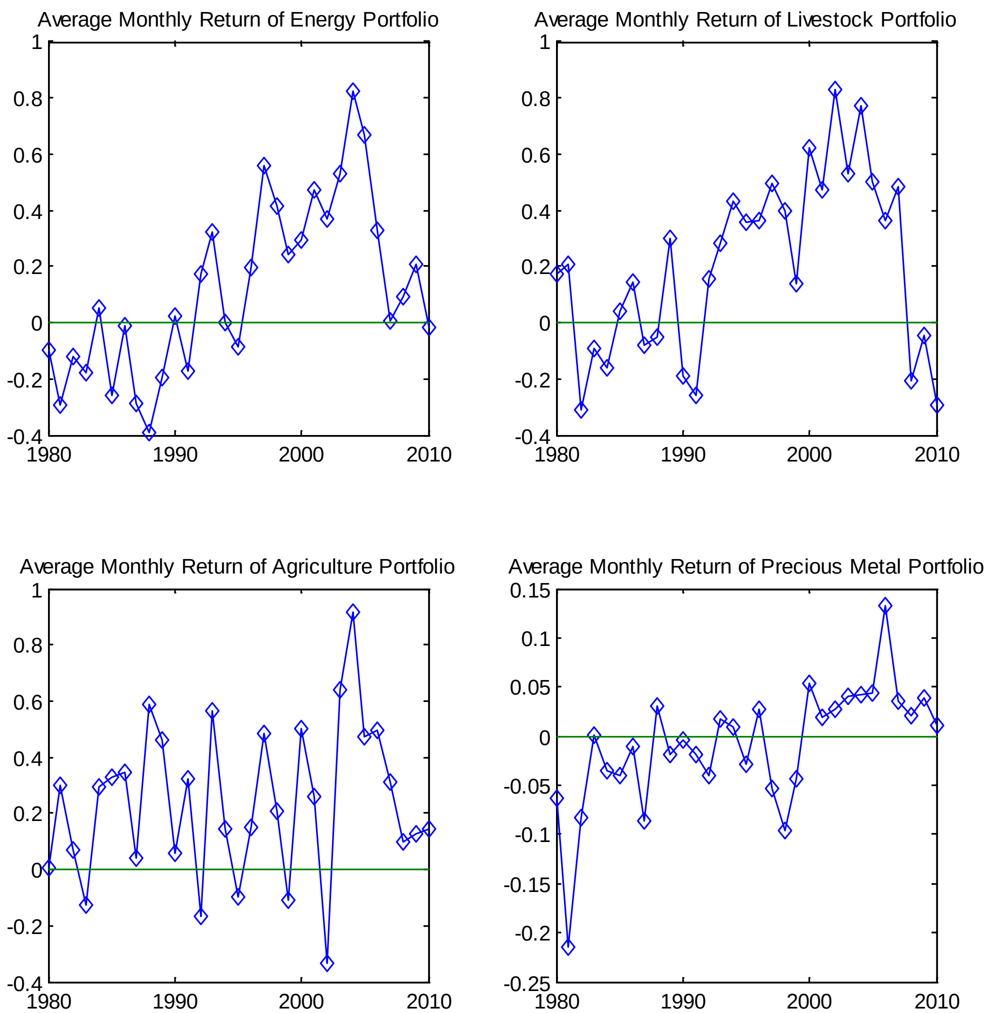


Figure 6: Average Number of Spread Position Taken by Speculators

This Figure plots the average number of spread positions taken by the trader category "Noncommercial" in the CFTC reports. These traders are labeled as speculators in literature, and mainly financial traders like hedge funds. The sample period is from Jan 1986 to March 2010.

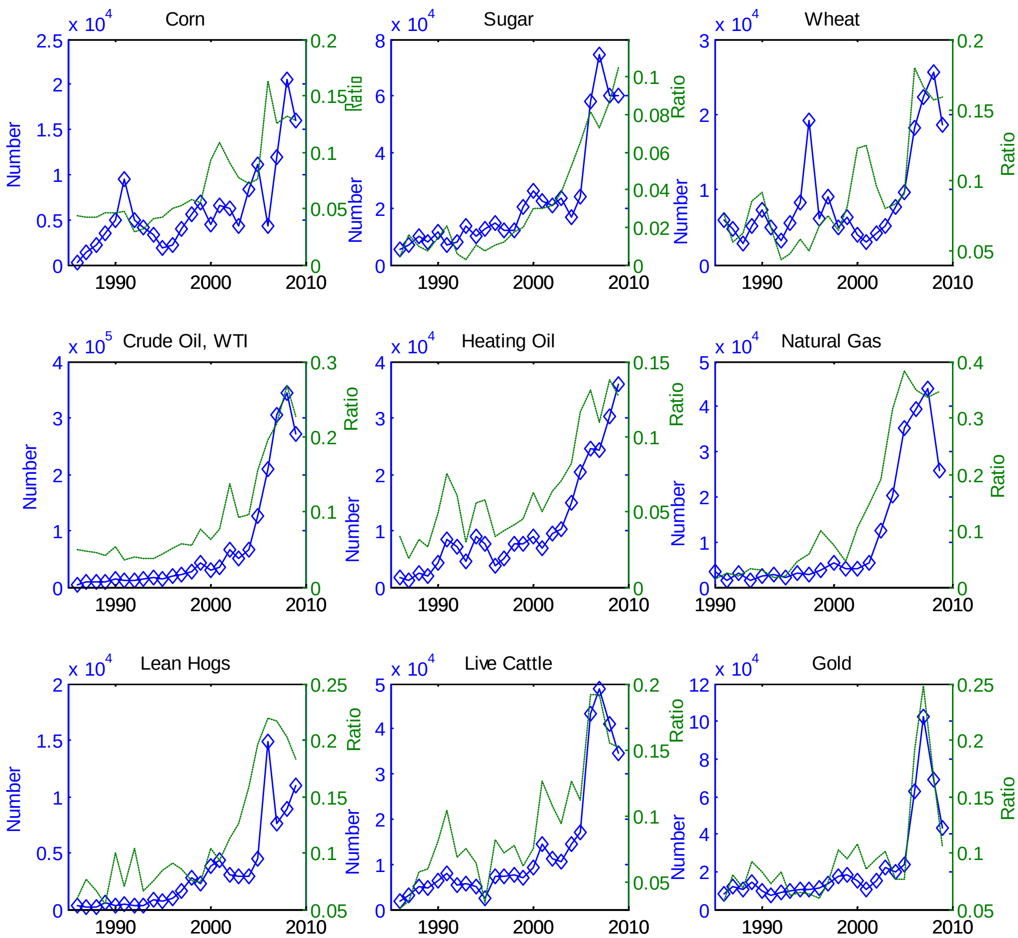
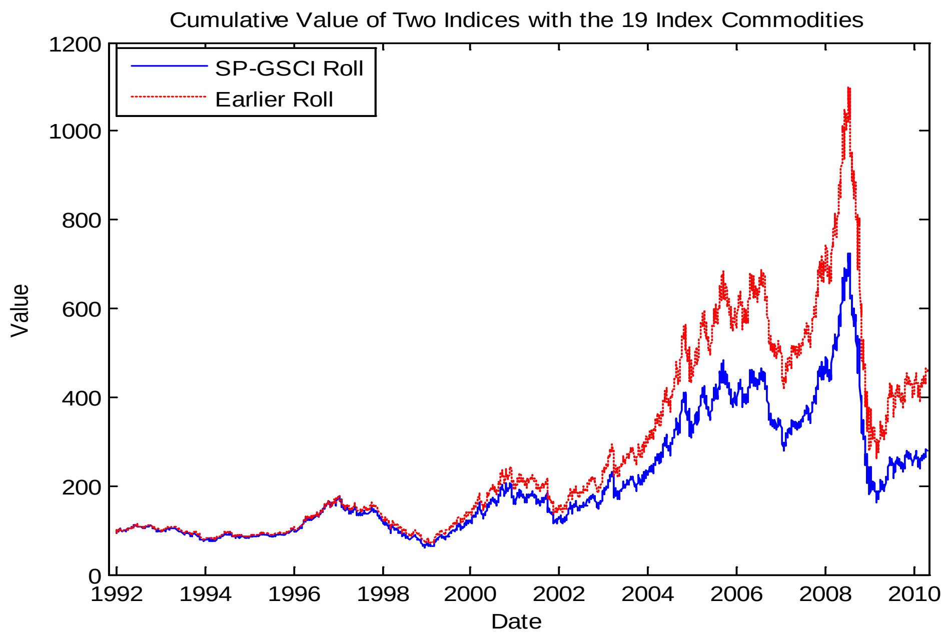


Figure 7: Value of Two Indices with Different Rolling Dates

This figure shows the value of two excess return indices: "SP-GSCI Roll" index and an "Earlier Roll" index. Both indices invested $100 dollars in commodity futures on Jan 2, 1992 and choose the same contracts as the SP-GSCI. The "SP-GSCI Roll" index rolls on the SP-GSCI's rolling dates, while the "Earlier Roll" index rolls 10 business days before the SP-GSCI's rolling dates. With the 19 index commodities, the commodities' weights are proportional to the weights in the SP-GSCI. With the 12 out-of-index commodities, equal weights are applied. There is no rebalancing, and the interest earned on collateral is not considered. Panel A shows the value of two indices with the 19 index commodities from Jan 1992 to Mar 2010. Panel B shows the value of two indices with the 12 out-of-index commodities from Jan 1992 to Sep 2009.



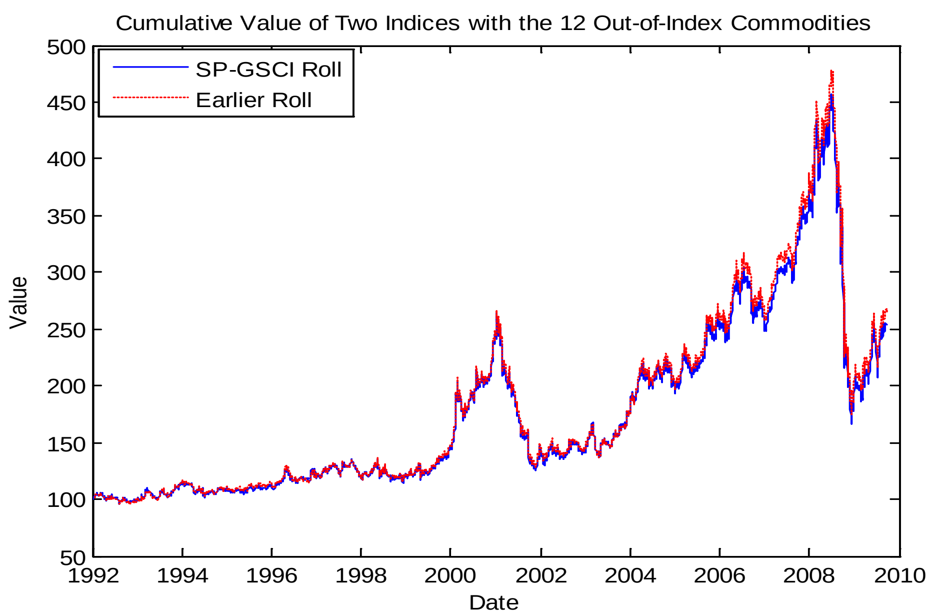


Figure 8: Estimated Size of Index Investment and Loss due to Price Pressure

This Figure shows the estimated size of total commodity index investment and loss due to the price impact of the Goldman Roll. The index investment data is compiled using source of Masters and White (2008) and the index investment reports from the CFTC, and the unit is billions of dollars. All investment is assumed to be tied to the “SP-GSCI Roll” index, and multiply it by the difference of average excess returns between the “SP-GSCI Roll” index and “Earlier Roll” index. The result is used to estimate the loss due to the price impact of the Goldman roll. The sample period is from 1991 to 2009.