Noise Trader Risk: Evidence from the Siamese Twins*

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Abstract

This paper provides new evidence regarding the magnitude and nature of noise trader risk. I examine returns for two pairs of "Siamese twin" stocks: Royal Dutch/Shell and Unilever NV/PLC. These unusual pairs of fundamentally identical stocks provide a unique opportunity to investigate the nature of noise trader risk. I investigate two facets of noise trader risk: (1) the fraction of total return variation unrelated to fundamentals (i.e., noise), and (2) the short-run risk borne by arbitrageurs engaged in long-short pairs trading. I report evidence that 30% of daily return variation and 10% of monthly return variation is attributable to noise. Noise trader risk has both systematic and firm-specific components, and varies considerably over time. The conditional volatility of long-short portfolio returns ranged from 0.4% to over 1.6% per day during the 1989–2003 sample period. Noise trader risk was especially high around the failure of Long-Term Capital Management in 1998 and during the collapse of the technology bubble in 2000. I conclude that noise trader risk is a significant limit to arbitrage.

Key Words: Noise trader risk; Market efficiency; Limits to arbitrage; Behavioral finance; Hedge funds.

JEL Classification: G12 (Asset Pricing); G14 (Information and Market Efficiency).

1 Introduction

Trading that is uncorrelated with changes in fundamental or intrinsic value is known as noise trading. Noise trading may occur for exogenous reasons (e.g., portfolio rebalancing, liquidity, etc.) or it may occur when investors trade on noise (e.g., changes in sentiment) as if it were information. To the extent that noise trading moves security prices, it contributes to return volatility. Noise trading now occupies an important place in the theory of finance. It has been a cornerstone of market microstructure theory since Kyle (1985). It has been suggested as an explanation for asset pricing "anomalies" such as the "excess volatility puzzle" first documented by Shiller (1981) and LeRoy and Porter (1981). And noise trading plays a central role in the burgeoning literature on behavioral finance. For example, De Long, Shleifer, Summers, and Waldman (1990) suggest that noise trader risk is a significant limit to arbitrage that may hinder informationally efficient markets. Black (1986) concludes that "Noise makes financial markets possible, but also makes them imperfect."

Despite its increasingly important role in finance, we have little empirical evidence regarding the magnitude or nature of noise trader risk. This is because it is difficult to empirically distinguish between fundamental shocks and noise shocks. In this paper, I circumvent this obstacle by exploiting a natural experiment: "Siamese twin" stocks. I examine two pairs of dual-listed securities: Royal Dutch/Shell and Unilever NV/PLC. Each of these twin stocks represents a nearly identical claim to a common cash flow stream. Thus, twin stocks have nearly identical risk exposures and should respond almost identically to news regarding fundamental value. The existence of twin stocks trading in different markets permits the investigation of two important facets of noise trader risk: (1) the fraction of total return variation unrelated to news about fundamentals (i.e., noise), and (2) the nature of the noise trader risk faced by arbitrageurs engaged in long-short pairs trading. Although twin stocks represent a very special case, the lessons learned have wider implications for asset pricing and market efficiency.

Twin stocks offer a model-free approach for estimating the contribution of noise trading to stock return volatility. Previous research in this area has produced mixed results. One branch of the literature (e.g., Cutler, Poterba, and Summers (1989), Roll (1988) and Fama (1990)) finds that news about fundamentals explains relatively little of the variation in total returns. For example, Roll (1988) reports that only 20% of the average large stock's daily return variation is attributable to fundamentals, and charges that "the paucity of explanatory power represents a significant challenge to our science." It is unclear whether the unexplained return variation reported in these papers is due to noise trading, or whether the empirical models do not fully account for all information relevant for valuation. In contrast, French and Roll (1986) conclude that noise trading is responsible for only a small fraction of daily return variation. Using variance ratios and daily return autocorrelations, French and Roll (1986) estimate that only 4% to 12% of daily return variation is attributable to noise trading. According to Fama (1991, p. 1580), 4% is "hardly a number on which to conclude that noise trading results in substantial market inefficiency."

In simple linear regressions, I find that about 70% of daily return variation can be explained by a twin stock. This explanatory power greatly surpasses that of the ex post information models examined by Cutler, Poterba, and Summers (1989), Roll (1988) and Fama (1990). However, a substantial fraction of return variation (about 30% for daily returns) remains unexplained by fundamentals. I attribute this unexplained variation to noise. For daily returns, this noise could be due to noise trading or transient microstructure-induced noise (e.g., bid-ask bounce, price discreteness, etc.). This figure far exceeds the upper bound estimated by French and Roll (1986). For weekly and monthly returns, the explained variation increases to nearly 90%. At these longer horizons, microstructure-induced noise should be relatively less important.

Due to their special nature, Siamese twin stocks also provide a unique opportunity to examine the role of noise trader risk as a limit of arbitrage. Because twin stocks represent nearly identical claims to a common cash flow stream, the law of one price implies that the ratio of twin stock prices should equal the theoretical parity ratio. No model of intrinsic value is required. Thus, the arbitrageur faces minimal bad-model risk and the joint-hypothesis critique (see Fama (1970, 1991)) doesn't apply. The arbitrageur also faces minimal fundamental risk. An appropriately constructed long-short relative value position should hedge out nearly all fundamental shocks.

Yet, we have observed large relative mispricings between twin stocks. These mispricings are often cited as puzzling violations of the law of one price (e.g., Shleifer (2000)). Rosenthal and Young (1990) document "significant and persistent" deviations from theoretical parity for Royal Dutch/Shell and Unilever NV/PLC for the period from September 1979 to December 1986. Froot and Dabora (1999) document mispricing through 1995 and find that "the relative price of twin stocks is highly correlated with the relative stock-market indexes of the countries where the twins' stocks are traded most actively."[1] Froot and Dabora (1999) examine a number of potential fundamental (i.e., rational) explanations for the observed deviations from parity. These fundamental explanations include discretion in the use of dividend income, differences between parent company expenditures, voting rights, foreign exchange risk exposure between dividend announcement and ex-dividend dates, differences in ex-dividend dates, and cross-border tax-induced investor heterogeneity. They conclude that none of these fundamental explanations are sufficient to explain the magnitude of the observed deviations from parity.

Violations of the law of one price are fascinating because they pose a fundamental empirical challenge to the efficient market hypothesis (EMH). The EMH implies that security prices should, on average, reflect fundamental value. In a frictionless and informationally efficient market, two essentially identical assets should trade for the same price. In theory, the law of one price is enforced by arbitrageurs. Arbitrageurs are rational traders who profit from simultaneously buying and selling essentially identical assets at different prices. The existence of such traders is perhaps the strongest theoretical foundation for the EMH. Shleifer (2000) neatly summarizes three theoretical arguments, each with progressively weaker assumptions, that justify the EMH. The first, and least plausible, argument assumes that all investors are rational. The second argument admits the existence of irrational traders, but assumes that their trades are random (i.e., uncorrelated) and, thus, do not affect equilibrium prices. The third argument admits the existence of irrational investors whose noise trading may be correlated. In such a market, prices could temporarily deviate from fundamental value. However, the third argument also assumes the existence of rational, well-capitalized arbitrageurs whose trades restore an equilibrium in which prices reflect intrinsic value. If arbitrage is limited, then correlated noise trading can move stock prices for reasons unrelated to news about fundamentals. Shleifer (2000) argues that violations of the law of one price suggest: (1) the presence of irrational investors (i.e., noise traders), and (2) limits to arbitrage. Potential limits to arbitrage include risks and trading costs. The risks, as described by Lamont and Thaler (2003), include bad-model risk, fundamental risk, and noise trader risk.[2] The trading costs include transaction costs, information costs, and financing costs.

The role of noise trader risk as an important limit to arbitrage is developed by De Long, Shleifer, Summers, and Waldman (1990), Shleifer and Vishny (1997), and Liu and Longstaff (2004). Liu

[1] These papers are the motivation for a fine case study by Froot and Perold (1996). Additional examples of dual-listed companies are analyzed by de Jong, Rosenthal, and van Dijk (2003).

[2] Lamont and Thaler (2003) examine apparent violations of the law of one price surrounding equity carve-outs and spin-offs in the tech industry.

and Longstaff (2004) consider the optimal investment decision of a risk-averse arbitrageur facing realistic collateral requirements. They show that the variance of long-short portfolio returns is an important determinant of the optimal arbitrage position. They conclude that it is often optimal to underinvest in arbitrage (i.e., take a smaller position than collateral requirements allow).

I employ a simple limited arbitrage-noise trader model to motivate my empirical framework. In this model, stock returns can be decomposed into four unobservable and orthogonal components: systematic fundamental shocks, firm-specific fundamental shocks, systematic noise shocks, and firm-specific (i.e., idiosyncratic) noise shocks. Barberis, Shleifer, and Wurgler (2005) suggest that noise traders invest in only a subset of available securities (i.e., their habitat). If arbitrage is limited, then noise trading induces systematic, sentiment-based comovement in the stock returns of a given habitat. These noise shocks are systematic in the sense that they are not diversifiable. However, systematic noise shocks for twin stocks trading in different habitats need not be correlated. Motivated by Rosenthal and Young (1990) and Froot and Dabora (1999), I assume that twin stocks are fundamentally identical (i.e., they respond identically to news about fundamental value). The most appealing aspect of this assumption is that no asset pricing model is required. A long-short portfolio of twin stocks should hedge the fundamental shocks (both systematic and firm-specific) and isolate the noise shocks. When twin stocks trade in distinct noise trader habitats, long-short portfolio returns will, in part, reflect the relative change in noise-trader sentiment (both systematic and firm-specific) across habitats. At short horizons, long-short portfolio returns will also include microstructure-induced noise.

I report three main results regarding the nature of noise trader risk faced by arbitrageurs engaged in long-short pairs trading. First, the magnitude of noise trader risk is surprisingly large. I define noise trader risk as the volatility (i.e., standard deviation) of daily returns for a long-short portfolio of twin stocks. An arbitrageur might reasonably use this measure in estimating portfolio value-at-risk. For 1989 to 2003, the sample standard deviation of a long-short portfolio of twin stocks is about 0.90% per day. For comparison, the volatility of a long-only, unhedged position in an individual twin stock is about 1.5% per day. Second, I find that noise trader risk has both systematic and firm-specific (i.e., idiosyncratic) components. Like Froot and Dabora (1999), I report evidence that long-short portfolio returns are correlated with the stock market indices and currencies of the markets where the twin stocks are traded most actively. This does not imply that long-short portfolios of twin stocks are fundamentally risky. In the habitat view of comovement, country-specific stock market indices contain a noise trader sentiment component. Thus, index returns are the sum of both fundamental and noise shocks. The limited arbitrage-noise trader model suggests that correlations between long-short portfolio returns and country-specific index returns are due to comovement in noise shocks, not comovement in fundamental shocks. The empirical evidence is consistent with this view. Third, I report new evidence that noise trader risk varies considerably over time. I extend the time-series models of Froot and Dabora (1999) to include GARCH processes for the conditional volatilities of the residuals. The conditional volatilities from these GARCH models are a reasonable estimate of the time-varying idiosyncratic noise trader risk faced by arbitrageurs engaged in long-short pairs trading. I find that this noise trader risk is highly persistent, and that the level of noise trader risk varied from 0.4% to 1.6% per day over the sample period. In particular, noise trader risk was very high during and following the failure of Long-Term Capital Management (LTCM) in 1998 and peaked around the collapse of the internet/technology bubble in 2000. The time-series patterns of conditional volatility are very similar for both pairs of twins. This suggests that the volatility of idiosyncratic noise shocks might share a common component.

It is unlikely that trading costs (i.e., transaction and financing costs) are a significant limit to arbitrage for twin stocks. Given the size and liquidity of the Siamese twins, transaction costs (e.g., bid-ask spreads, transaction fees, transaction taxes, market impact costs) alone are unlikely to impede trading or explain the magnitude of the observed deviations from parity. Since convergence is not assured, financing costs (i.e., costs of carry) are a potentially important trading cost. Since exploiting the observed mispricings involves a long-short position, the costs of shorting the relatively overpriced twin are particularly important. Since the relatively overvalued twins (i.e, Royal Dutch and Unilever NV) for most of the sample period were components of the S&P 500, they were easy to borrow and cheap to short. Therefore, it is unlikely that either transaction costs or financing costs are sufficient to explain observed deviations from theoretical parity.

Much of the existing empirical literature on limits to arbitrage has focused on evidence from a different natural experiment: closed-end funds. For example, Lee, Shleifer, and Thaler (1991) employ a limited arbitrage-noise trader model to explain discounts/premiums on closed-end funds. The evidence reported in this paper is unique for two reasons. First, trading costs are a significant limit to arbitrage for closed-end funds (Pontiff (1996)). However, trading costs are not a substantial obstacle to long-short pairs trading in twin stocks. This leads me to conclude that noise trader risk is an important limit to arbitrage. This view is consistent with Pontiff (2006), who suggests that idiosyncratic risk is the single largest cost faced by arbitrageurs. Second, the question of whether discounts on closed-end funds are rational or irrational is still being hotly debated. Berk and Stanton (2005) provide a recent summary of the various rational explanations suggested to explain the closed-end fund anomaly. In contrast, I am aware of no serious challenge to Froot and Dabora's (1999) conclusion that rational explanations are unlikely to explain the magnitude of observed deviations from parity for Royal Dutch/Shell and Unilever NV/PLC.

Finally, I relate my findings to the failure of Long-Term Capital Management (LTCM) in 1998. Hedge funds such as LTCM are known to have engaged in pairs trading to profit from relative mispricings of Royal Dutch/Shell and Unilever NV/PLC. Yet, despite heavy trading by well-capitalized arbitrageurs, relative mispricings persisted and even increased. I find that the widening Siamese twin arbitrage spreads associated with the demise of LTCM were accompanied by very high levels of noise trader risk.

The remainder of the paper is organized as follows. Section 2 discusses the nature of Royal Dutch/Shell and Unilever NV/PLC, and shows that previously documented deviations from theoretical parity have persisted. Section 3 develops a simple limited arbitrage-noise trader model of stock returns. In this model, stock returns are the sum of four orthogonal components: systematic fundamental shocks, firm-specific fundamental shocks, systematic noise shocks, and firm-specific noise shocks. Section 4 explores two facets of noise trader risk. First, I examine the degree to which total return variation is explained by the returns of twin stocks. Second, I examine the volatility of hypothetical long-short portfolios in twin stocks. Trading costs associated with arbitrage, including transaction and financing costs, are discussed in Section 5. Section 6 considers LTCM's widely-reported Royal Dutch/Shell relative value trade. This fascinating episode provides additional insight into the role of noise trader risk as a limit to arbitrage. In Section 7, I summarize the paper's results and discuss the implications for market efficiency.

2 The Siamese Twins

A Royal Dutch Petroleum and Shell Transport and Trading, PLC

Prior to its 2005 unification, the Royal Dutch/Shell Group was jointly held by two holding companies: Royal Dutch Petroleum Company (Royal Dutch) and The Shell Transport and Trading Company (Shell Transport). Royal Dutch, domiciled in the Netherlands, had an interest of 60% in the Group. Shell Transport, domiciled in the United Kingdom, had a 40% interest in the Group. Arrangements between Royal Dutch and Shell Transport provided for aggregate dividends to be divided 60:40. Froot and Dabora (1999) discuss these arrangements in detail.[3] The 60:40 division of a common cash flow stream allows us to estimate the theoretical parity relation between the stock prices of the twin holding companies. If the law of one price holds, then the theoretical ratio of the price of an ordinary share of Royal Dutch to the price of an ordinary share of Shell Transport (expressed in a common currency) is:

$$\text{Theoretical Parity} = \frac{(0.6)(\text{Shell Transport shares outstanding})}{(0.4)(\text{Royal Dutch shares outstanding})}$$

My definition of mispricing is simply the deviation of the actual price ratio (expressed in a common currency) from the theoretical parity relation.

In Europe, Royal Dutch ordinary shares traded primarily on the Amsterdam Stock Exchange (ASE symbol: RDA) and Shell Transport ordinary shares traded primarily on the London Stock Exchange (LSE symbol: SHEL). In the United States, Royal Dutch ordinary shares were traded in registered form on the New York Stock Exchange and were referred to as "New York shares" (NYSE symbol: RD). Shell Transport ordinary shares were traded as American Depository Receipts (ADRs) on the NYSE. Each PLC ADR (NYSE symbol: SC) represented six Shell Transport ordinary shares. It follows that the parity relation between Royal Dutch "New York shares" and Shell Transport ADRs is one-sixth the parity relation for Amsterdam/London shares. Although most Royal Dutch shares (approximately 59% of outstanding shares in 2001) were registered in Amsterdam, a substantial fraction (approximately 40%) were registered in the United States (Royal Dutch/Shell Form 20-F filings). For Shell Transport, approximately 96% of outstanding shares

[3] The 2005 unification of Royal Dutch and Shell Transport resulted in a single company, Royal Dutch Shell, with two classes of common stock ("A" and "B" shares). This paper examines data collected prior to the unification announcement.

were registered in London and only 4% were registered in the United States.

The top panel in Figure 1 plots daily deviations from theoretical parity for Royal Dutch/Shell for the period January 4, 1989 to March 5, 2004. The deviations from parity are positive for most of the sample period, indicating that Royal Dutch traded at a premium relative to Shell Transport. The deviations are based on closing stock prices in Amsterdam and London (provided by Datastream), and the guilder-to-pound or euro-to-pound exchange rate (provided via Datastream by WM/Reuters).[4] The plot confirms and extends evidence of significant and persistent deviations from parity previously reported by Rosenthal and Young (1990) and Froot and Dabora (1999). The deviation from parity briefly exceeded 20% in October 1998. This peak occurred shortly after the takeover/recapitalization of LTCM.

B Unilever NV and Unilever PLC

Unilever NV and Unilever PLC are the twin parent companies of the Unilever Group. The Unilever Group originated from the 1930 merger of Margarine Unie, a Dutch margarine producer, and Lever Brothers, a British soapmaker. To ensure that the Unilever NV and Unilever PLC operate for all practical purposes as a single company, they are governed by an equalization agreement. The two firms share the same board of directors, the same reporting periods, and the same accounting policies. Neither parent is allowed to issue or reduce capital without the permission of the other. The equalization agreement provides that "one NV ordinary share equates to 6.67 ordinary shares of PLC" (Unilever Form 20-F). It follows that the theoretical parity relation between the share prices of Unilever NV and Unilever PLC (expressed in a common currency) is fixed at 6.67:1.

In Europe, NV ordinary shares trade primarily on the Amsterdam Stock Exchange (ASE symbol: UNA) and PLC ordinary shares trade primarily on the London Stock Exchange (LSE symbol: ULVR). In the United States, NV ordinary shares are traded in registered form on the New York Stock Exchange and are referred to as "New York shares" (NYSE symbol: UN). PLC ordinary shares are traded as American Depository Receipts (ADRs) on the NYSE. Each PLC ADR (NYSE symbol: UL) represents four ordinary PLC shares. It follows that the theoretical parity relation between NV New York shares and PLC ADRs is 1.67:1. According to Unilever Form 20-F filings, the majority (approximately 72% in 2001) of Unilever NV shares are registered in Amsterdam. Approximately 28% are registered in the United States. In contrast, 99% of Unilever PLC shares

[4]The plot of deviations from parity based on closing prices in New York is nearly identical.

are registered in London.

The bottom panel of Figure 1 plots daily deviations from theoretical parity for Unilever NV/PLC for the period January 4, 1989 to March 5, 2004. Positive deviations indicate that Unilever NV is trading at a premium relative to Unilever PLC. The deviations are based on closing prices in Amsterdam and London.[5] As was the case with Royal Dutch/Shell, the plot confirms and extends evidence of significant and persistent deviations from parity previously reported by Rosenthal and Young (1990) and Froot and Dabora (1999). The positive deviation became pronounced in 1996 and remained so until the deletion of Royal Dutch and Unilever NV from the S&P 500 Index in July 2002.

3 Model

In this section, I develop a simple model to formalize the intuition provided in the introduction. The model is similar in spirit to the limited arbitrage-noise trader model in Barberis, Shleifer, and Wurgler (2005). Let the return on stock i be the sum of four orthogonal and unobservable components:

$$r_{i,t} = \underbrace{\overbrace{u_{i,t}}^{\text{fund.}} + \overbrace{\eta_{i,t}}^{\text{noise}}}_{\text{systematic}} + \underbrace{\overbrace{w_{i,t}}^{\text{fund.}} + \overbrace{\varepsilon_{i,t}}^{\text{noise}}}_{\text{firm-specific}}. \tag{1}$$

$u_{i,t}$ is the systematic fundamental shock. It represents the change in fundamental value due to innovations in economy-wide risk factors. Although it is not necessary to assume any further structure regarding the fundamental return generating process, one might think of this shock as the outcome of a factor model (e.g., $u_{i,t} = Bf_t$ where f_t is a vector of systematic factor shocks and B is the corresponding factor loading matrix). In the traditional view, covariance between asset returns is driven by comovement in news about fundamentals. Systematic fundamental shocks are not diversifiable.

$w_{i,t}$ is the firm-specific fundamental shock. It represents the firm-specific change in fundamental value. Firm-specific fundamental shocks are assumed to be uncorrelated across stocks, and thus, diversifiable.

[5]The plot of deviations from parity based on closing prices in New York is nearly identical.

$\eta_{i,t}$, the systematic noise shock, represents the change in noise trader sentiment regarding stock i that is: (1) orthogonal to fundamental news regarding stock i, and (2) correlated with changes in noise trader sentiment regarding other stocks. To the extent that such shocks are correlated across stocks, they are not diversifiable. As an alternative to the traditional (or fundamental) view of stock return comovement, Barberis, Shleifer, and Wurgler (2005) suggest "friction-based" and "sentiment-based" explanations for return comovement. In one explanation, the habitat view, noise traders only invest in a subset of available securities. Their noise trading induces sentiment-based comovement in the returns of stocks in that habitat. A domestic stock market is a natural example of a habitat for noise traders. American and Dutch noise traders might invest in Royal Dutch or Unilever NV, while British noise traders invest in Shell or Unilever PLC. A stock market index is another example of a habitat. For example, an S&P 500 index fund would invest in index constituents such as Royal Dutch and Unilever NV, but not in their twins. Many other funds are effectively quasi-indexers due to tracking error constraints in performance incentive contracts. Correlated noise trading in index constituents will induce sentiment-based comovement in those stocks (Barberis, Shleifer, and Wurgler (2005)). Thus, index returns can also be decomposed into fundamental and noise shocks.

$\varepsilon_{i,t}$ is the firm-specific or idiosyncratic noise shock. It includes the firm-specific component of the change in noise trader sentiment regarding stock i. It also includes possible microstructure effects (e.g., bid-ask bounce) and other idiosyncratic noise. Firm-specific noise shocks are diversifiable.

It should be emphasized that fundamental shocks ($u_{i,t}$ and $w_{i,t}$) are unobservable. Only the return $r_{i,t}$ is observable. In order to isolate and study noise shocks, one must assume a model of fundamental value. The inherent difficulty of this task is largely responsible for the paucity of empirical evidence regarding the magnitude and nature of noise in stock returns. Twin stocks provide a natural experiment for studying the nature of noise trader risk. Motivated by Rosenthal and Young (1990) and Froot and Dabora (1999), I simply assume that twin stocks are fundamentally identical. Let $r_{A,t}$ and $r_{B,t}$ denote the returns of twin stocks trading in habitats A and B. The assumption that A and B are twin stocks implies that their fundamental shocks, both systematic and firm-specific, are identical for each period:

$$\begin{aligned} u_{A,t} &= u_{B,t} \quad \forall\, t \\ w_{A,t} &= w_{B,t} \quad \forall\, t. \end{aligned}$$

Now consider the returns on a long-short portfolio of twin stocks. The assumption that A and B are twins implies that the fundamental shocks are perfectly hedged, and that the long-short portfolio return isolates the noise shocks:

$$
\begin{aligned}
r_{A-B,t} &= r_{A,t} - r_{B,t} \\
&= (\eta_{A,t} - \eta_{B,t}) + (\varepsilon_{A,t} - \varepsilon_{B,t}). \qquad (2)
\end{aligned}
$$

Equation (2) indicates that relative changes in noise trader sentiment between habitats A and B contribute to long-short portfolio volatility. The $(\varepsilon_{A,t} - \varepsilon_{B,t})$ term also captures the contribution of other idiosyncratic noise. Using long-short portfolio returns, it is not possible to distinguish between fundamental shocks and a common component in noise shocks. To the extent that noise shocks are correlated between twin stocks, they will be indistinguishable from fundamental shocks. Thus, long-short portfolio returns will understate the amount of noise trader risk in stock returns.

The table below presents a taxonomy summarizing the risks faced by an arbitrageur engaged in long-short pairs trading:

	Fundamental Risk	Noise Trader Risk
Systematic Risk	Hedged Non-Diversifiable	Not Hedged Non-Diversifiable
Firm-Specific Risk	Hedged Diversifiable	Not Hedged Diversifiable

This taxonomy suggests that a hedge fund with a diversified portfolio of long-short arbitrage trades may still bear considerable systematic noise trader risk.

In theory, arbitrageurs enforce the law of one price and assure that stock prices reflect fundamental value. This is perhaps the strongest theoretical justification for the efficient markets hypothesis. If markets are frictionless and arbitrage is not limited, then the law of one price should hold exactly at every point in time and noise trader sentiment shouldn't affect market prices. This implies that the volatility of long-short portfolio returns should be zero. In the presence of market frictions (e.g., transaction costs, microstructure effects, etc.), the law of one price should hold approximately. Relative mispricing shouldn't exceed transaction cost bounds and the volatility of long-short portfolio returns should reflect the magnitude of market frictions.

If arbitrage is limited, then changes in noise trader sentiment can move stock prices independently of changes in fundamental value (De Long, Shleifer, Summers, and Waldman (1990), Shleifer and Vishny (1997)). For twin stocks, differences in noise trader sentiment across habitats can lead to violations of the law of one price such as those depicted in Figure 1. In terms of equation (2), relative changes in noise trader sentiment between habitats enter into the long-short portfolio return. The returns of portfolios affected by noise trader sentiment in habitat A (habitat B) will be positively (negatively) correlated with long-short portfolio returns. These correlations are not due to comovement in fundamentals. Thus, they are not indicative of systematic risk in the traditional sense. The correlations are due to comovements in noise trader sentiment.

In related research, Lee, Shleifer, and Thaler (1991) employ a limited arbitrage-noise trader model to explain discounts/premiums on closed-end funds. Their model hinges on two assumptions: (1) arbitrage is costly, and (2) closed-end funds are traded primarily by individual investors (a distinct habitat for noise traders), while the constituent stocks of those funds are traded primarily by investors from a different noise trader habitat. The model predicts that closed-end fund discounts and premiums are related to differences in noise trader sentiment across habitats.

The analysis above assumes that information regarding fundamentals, both public and private, is impounded into twin stock prices simultaneously. This is a strong assumption. Many standard theoretical models suggest that price adjustment to private information is not instantaneous. For example, the monopolist informed trader in Kyle (1985) behaves strategically. Thus, private information is only gradually impounded into prices. Competition between multiple informed traders generally results in more aggressive trading and faster revelation of private information (see Grossman and Stiglitz (1980) and Holden and Subrahmanyam (1992)). This suggests that the speed with which private information is impounded into stock prices is related to the number of informed traders. If the number of strategic informed traders differs across habitats, then private information regarding twins stocks might be revealed at different rates. Such segmentation might arise due to differences in trading costs or differences in market maker behavior.

What happens to the long-short portfolio returns in (2) when private information is impounded into twin stock prices at different rates? For notational convenience, let $v_{i,t} = u_{i,t} + w_{i,t}$ be the combined (i.e., systematic plus firm-specific) fundamental shock from equation (1). Assume that stock A fully and immediately impounds information about fundamental value, but that stock B

impounds fraction μ of the fundamental news immediately and the remainder one period later:

$$v_{B,t} \quad = \quad \mu v_{A,t} + (1-\mu) v_{A,t-1} \quad \forall\, t.$$

In this case, the long-short portfolio return is:

$$r_{A-B,t} \quad = \quad (1-\mu) v_{A,t} - (1-\mu) v_{A,t-1} + (\eta_{A,t} - \eta_{B,t}) + (\varepsilon_{A,t} - \varepsilon_{B,t}). \tag{3}$$

If twin stocks impound information about fundamental value in this manner, then long-short portfolio returns will exhibit negative first-order serial correlation. The empirical models developed in the next section include a lagged dependent variable to account for this possibility.

4 Empirical Results

Siamese twin stocks provide a unique opportunity to explore the nature of noise and noise trader risk. I examine two facets of noise trader risk: (1) noise as the unexplained component of total return variation, and (2) the short-run risk faced by arbitrageurs engaged in long-short pairs trading.

A Noise in Twin Stock Returns

Table 1 reports sample statistics describing the return volatility of the individual twin stocks. Panel A of Table 1 reports results for two sets of daily log total returns. The first set of returns is based on closing prices in Amsterdam and London for the period January 3, 1989 to March 5, 2004. The second set of returns is based on closing prices in New York for the period January 4, 1989 to December 31, 2003. The volatility of individual stock returns is moderate. Daily sample standard deviations range from 1.47% to 1.56% per day. Assuming that returns are independent and identically distributed, these figures correspond to annualized standard deviations of roughly 23 to 25 percent per year. First-order serial correlations for the individual stock daily returns are not excessive, and most are not significantly different than zero. This is not surprising. These stocks are large, liquid and heavily-traded. It follows that their daily returns are less likely to be affected by the bid-ask bounce or infrequent trading problems that arise in some daily stock return series. Sample correlations between the daily returns of twin pairs are high (all are greater than 0.8), but far from perfect (all are less than 0.9). Panels B and C of Table 1 repeat this analysis for weekly and monthly returns from January 1989 to December 2003. Sample standard deviations range from 2.79% to 3.57% per week and from 5.83% to 6.79% per month. These figures correspond to annualized standard deviations of 20 to 24 percent per year. Sample correlations between the twin stock returns range from 0.89 and 0.94 for weekly and monthly returns.

Several studies (e.g., Cutler, Poterba, and Summers (1989), Roll (1988) and Fama (1990)) have attempted to estimate the variation in stock returns attributable ex post to news about fundamentals. The results are typically disappointing for proponents of the efficient markets hypothesis. For example, Roll (1988) finds that a surprisingly low fraction of a typical large stock's variance is explained by systematic risk factors, returns of other stocks in the same industry, and public firm-specific news events. He reports that the average adjusted R^2 statistic for large stocks is only about 20% with daily data and less than 40% with monthly data. Roll concludes that the "paucity of explanatory power represents a significant challenge to our science." He challenges the profession to "discover either (a) measurable influences that will explain the remaining sixty percent, or (b) a coherent reason why it should forever remain unexplained."

Siamese twin stocks offer a unique, model-free approach for estimating the fraction of stock return variation attributable to news about fundamentals. If twin stocks respond identically to news about fundamental value, then the returns of one twin stock should explain the returns of the other. It is not necessary to explicitly model the process by which news is impounded into stock prices. I employ ordinary least squares (OLS) regressions to estimate the relation between twin stock returns:

$$r_{A,t} = \alpha + \theta_{-1} r_{B,t-1} + \theta_0 r_{B,t} + \theta_1 r_{B,t+1} + \varepsilon_t \tag{4}$$

where $r_{A,t}$ and $r_{B,t}$ are log total returns for pairs of twin stocks. For Amsterdam/London returns, the Amsterdam-listed stock's return is converted to pounds sterling by subtracting the log change in the guilder-to-pound (or euro-to-pound) exchange rate. For daily returns, I include lead and lagged twin returns as additional independent variables to account for potential differences in the speed with which news is impounded into stock prices.

Table 2 reports OLS estimates of equation (4). Panel A reports results for Amsterdam/London daily returns and Panel B reports results for New York daily returns. The daily return results are similar for European and American markets. Adjusted R^2 statistics are around 70% for daily returns. Thus, I attribute a relatively high fraction of daily return variation to news about fundamentals. Estimates of the coefficient θ_0 range from 0.78 to 0.90. The coefficients on the lead and lagged twin returns are typically small (less than 0.1), but significant. However, the hypothesis $\Sigma\theta_i = 1$ can be rejected for most of the daily return models. Although the adjusted R^2 statistics are high relative to previous studies (e.g., Roll (1988) found that only 20% of the variation in daily returns was explained by news about fundamentals), much of the variation in daily returns remains unexplained. I attribute the "unexplained" variation in daily returns to noise. The 30% of daily return variation that I attribute to noise is much higher than the upper bounds estimated by French and Roll (1986). French and Roll (1986) use variance ratios (e.g, six-month returns vs. daily returns) and daily autocorrelations to estimate that 4.1% to 11.7% of daily return variation is due to noise trading for the average stock. For stocks in the largest market capitalization quintile (such as the twins), they estimate that noise trading is responsible for 6.7% to 9.3% of daily return variation. However, these estimates are based on the assumption that pricing errors and bid/ask errors are temporary (i.e., transient) and have a negligible effect on six-month returns. In other words, French and Roll (1986) assume that pricing errors due to noise trading are corrected over a relatively short horizon. This assumption is questionable. The relative mispricings depicted in Figure 1 clearly persist for much longer than six months. If temporary pricing errors due to noise trading are highly persistent, then the fraction of daily return variation attributable to noise trading may be much higher than the upper bounds estimated by French and Roll (1986).

Table 3 reports OLS estimates of equation (4) for weekly and monthly returns in Amsterdam/London and New York. The lead and lagged twin stock returns are omitted for these longer horizons. The sample period is January 1989 to December 2003 (682 weekly observations and 180 monthly observations). Explanatory power is higher for weekly/monthly returns than for daily returns; adjusted R^2 statistics range from 83% to 87% for weekly returns and from 86% to 90% for monthly returns. This is consistent with some, but not all, daily noise shocks being reversed within a month.

B Amsterdam/London Long-Short Portfolio Daily Returns

For the remainder of this section, I consider the risk faced by arbitrageurs engaged in long-short pairs trading in Siamese twin stocks. Let $r_{A-B,t}$ be the total log return on the Amsterdam-listed twin (i.e., Royal Dutch or Unilever NV) less the log total return on the London-listed twin (i.e., Shell Transport or Unilever PLC) expressed in a common currency. I loosely interpret $r_{A-B,t}$ as the gross return on a self-financing arbitrage portfolio.[6] In this subsection, I analyze the risk of long-short portfolios formed in European markets. Given the relatively low ownership of Shell Transport and Unilever PLC outside of the UK, European markets were likely the most attractive venue for establishing large arbitrage positions during the period under study. Total returns for Royal Dutch, Unilever NV and the AEX index are observed at the close of trading (1630 GMT) in Amsterdam. Total returns for Shell Transport, Unilever PLC and the FTSE 100 index are observed at the close of trading (1630 GMT) in London. Exchange rates, provided by WM/Reuters, are observed in London at 1600 GMT. The closing level for the S&P 500 index is observed in New York at 2100 GMT. All data are obtained from Datastream.[7] The sample period is January 3, 1989 to March 5, 2004.

The sample standard deviation of daily long-short portfolio returns (reported in Table 1) is 0.88% per day for the Royal Dutch/Shell pair and 0.93% per day for the Unilever NV/PLC pair. Note that these raw Amsterdam/London long-short portfolio returns are exposed to foreign exchange risk. However, when long-short portfolio returns are expressed in a common currency (by subtracting log changes in the guilder-to-pound or euro-to-pound exchange rate), the sample standard deviations change very little (0.86% per day for Royal Dutch/Shell and 0.91% per day for Unilever NV/PLC). Given that the sample standard deviations for individual twin stock returns are about 1.5% per day, the magnitude of the long-short portfolio standard deviations is somewhat surprising. However, it is consistent with the less than perfect correlations between pairs of twin stocks reported in Table 1. Assuming that that long-short portfolios of twin stocks hedge out fundamental risk, what remains is a reasonable estimate of noise trader risk. An arbitrageur engaged in long-short pairs trading might reasonably use the sample standard deviation of long-short portfolio returns as an input into a delta-normal value-at-risk calculation. Unlike the returns of the individual stocks, daily long-short portfolio returns exhibit significant negative serial correlation. First-order serial correlation coefficients range from -0.213 to -0.305 in Amsterdam/London. As shown in Section 3, negative serial correlation in long-short portfolio returns is consistent with

[6] This definition of arbitrage returns implicitly assumes that the position is rebalanced daily. Since I am concerned with the risk and not the performance of long-short portfolios, this assumption is of little consequence. The concept of a return on a zero net investment arbitrage portfolio requires some explanation. The long-short portfolio returns are relative to the amount of the long exposure.

[7] Total log returns for Amsterdam and London are constructed from the Datastream return index (RI). I omit dates on which exchanges in either Amsterdam or London are closed before computing log total returns. Consider an example in which date t is an exchange holiday in Amsterdam, but not London. The total returns for that period would be log changes in total return indices from date $t-1$ to date $t+1$. This procedure insures that both twins are traded each period and minimizes spurious relations that can arise due to non-trading in one market.

information not being impounded into stock prices simultaneously. It is also interesting to note that the long-short portfolio returns for Royal Dutch/Shell and Unilever NV/PLC are correlated with each other. The correlation is 0.312 in Amsterdam/London after converting to a common currency. This suggests that long-short portfolio returns share a common component.

I next decompose long-short portfolio returns into systematic and idiosyncratic components. The empirical model is based on Froot and Dabora (1999). The dependent variable, $r_{A-B,t}$, is the log total return on the Amsterdam-listed twin (i.e., Royal Dutch or Unilever NV) less the log total return on the London-listed twin (i.e., Shell Transport or Unilever PLC). Following Froot and Dabora (1999), the return is expressed in a common currency by subtracting the log change in the guilder-to-pound (or euro-to-pound) exchange rate. For European markets, the only non-synchronous independent variable is the log total return on the S&P 500 index. I include an additional lagged observation of the S&P 500 return to account for this non-synchronicity. The Amsterdam/London specification is:

$$r_{A-B,t} = \alpha + \phi r_{A-B,t-1} + \sum_{i=-1}^{0} \beta_i S\&P_{t+i} + \delta FTSE_t + \lambda AEX_t + \gamma Fl./\$_t + \nu Fl./£_t + \varepsilon_t \qquad (5)$$

where $S\&P$ is the log total return on the S&P 500 index, $FTSE$ is the log total return on the FTSE 100 index, AEX is the log total return on the Amsterdam stock index, $Fl./\$$ is the log change in the guilder-to-dollar exchange rate, and $Fl./£$ is the log change in the guilder-to-pound exchange rate. After adoption of the euro on January 1, 1999, $Fl./\$$ and $Fl./£$ are replaced by $€/\$$ and $€/£$, respectively. I include the lagged dependent variable to account for the first-order serial correlation evident in Table 1. I extend the Froot and Dabora (1999) model by assuming that the errors in (5) are conditionally heteroskedastic. Specifically, I assume that the conditional variance follows a GARCH(1,1) process:

$$\begin{aligned} \varepsilon_t &\sim \mathcal{N}(0, h_t) \\ h_t &= c + a h_{t-1} + b\varepsilon_{t-1}^2. \end{aligned} \qquad (6)$$

Under the null hypothesis, markets are frictionless and informationally efficient.[8] This null hypothesis implies that the coefficients on the index returns and changes in exchange rates should all be equal to zero (i.e., no excessive comovement). In the case of the S&P 500 return, the null

[8]Froot and Dabora (1999) refer to this null hypothesis as "no international segmentation."

hypothesis implies that $\beta_{-1} + \beta_0 = 0$.

The sentiment-based habitat view of comovement makes different predictions regarding the coefficients in (5). It seems reasonable that the Amsterdam, New York and London markets represent distinct habitats for different groups of noise traders. Royal Dutch and Unilever NV trade primarily in Amsterdam and New York, while Shell Transport and Unilever PLC trade primarily in London. If arbitrage is limited, the habitat view predicts that the returns of portfolios affected by noise trader sentiment in Amsterdam and New York will be positively correlated with long-short portfolio returns. In terms of (5), this implies that $\beta > 0$, $\delta > 0$, and $\gamma > 0$.[9] Likewise, the habitat view predicts that the returns of portfolios affected by noise trader sentiment in London will be negatively correlated with long-short portfolio returns. This implies $\lambda < 0$ and $\nu < 0$. It is important to emphasize that these predicted correlations are due to comovements in noise trader sentiment, not comovements in news regarding fundamental value.

Panel A of Table 4 reports Amsterdam/London time-series regression results for Royal Dutch/ Shell and Unilever NV/PLC. The results for both pairs of twins are similar, so I discuss them together. First, I confirm Froot and Dabora's finding that long-short portfolio returns exhibit "excessive comovement" with the index where the twins' stock is traded most actively. The returns are strongly related to the Amsterdam AEX index and inversely related to the London FTSE 100 index. I also find evidence of "excessive comovement" with the S&P 500 index. For both pairs of twins, the relations with the S&P 500 and the guilder-to-dollar (or euro-to-dollar) exchange rate are positive and significant. Royal Dutch and Unilever NV are heavily traded in New York and were components of the S&P 500 index until July 2002. The long-short portfolio returns are strongly inversely related to log changes in the guilder-to-pound (or euro-to-pound) exchange rate. This indicates that differences in twin prices (measured in domestic currencies) respond less than fully to changes in the guilder-to-pound (or euro-to-pound) exchange rate. This result is also consistent with Froot and Dabora (1999). The significant negative coefficient on the lagged dependent variable is consistent with the first-order serial correlation reported in Table 1, and may indicate that information is not impounded simultaneously into twin stock prices. The adjusted R^2 statistic is 28.0% for Royal Dutch/Shell and 24.3% for Unilever NV/PLC. The sample correlation between the two series of residuals is 0.146. This indicates that even after controlling for changes in stock indices and exchange rates, the long-short portfolio returns share a common component.

[9] The log return (in guilders) on the S&P 500 is the sum of $S\&P$ and $Fl./\$$. Thus, the habitat view predicts the same sign for both coefficients.

This evidence suggests that a small, but significant, fraction of the noise trader risk in long-short portfolios of twin stocks is systematic. This does not imply that long-short portfolios of twin stocks are exposed to fundamental risk. Rather, the significant comovement between long-short portfolio returns and stock index returns reported in Table 4 is consistent with the habitat view of comovement. Froot and Dabora (1999) report similar results and suggest two possible sources of international segmentation that might explain these findings. The first is country-specific noise shocks. If a country-specific noise shock disproportionately affects the twin that trades more heavily in that country's market, then the relative mispricing between the twins should be correlated with that country's market index. This implies that deviations from parity may reflect the cumulative effect of correlated noise trading. The second possible source of international segmentation arises from institutional frictions. If fund managers face investment restrictions (e.g., invest in only domestic stocks) or are benchmarked against indices (e.g., the S&P 500 or the FTSE), these frictions may bias demand for certain stocks and explain deviations from the law of one price. Froot and Dabora's explanations are consistent with the "sentiment-based" and "friction-based" views of comovement in Barberis, Shleifer, and Wurgler (2005).

The GARCH(1,1) equation parameter estimates reported in Panel A of Table 4 are similar for Royal Dutch/Shell and Unilever NV/PLC. The conditional variance processes are highly persistent. Estimates of the persistence parameter a range from 0.953 to 0.967, and the GARCH(1,1) parameters $(a + b)$ sum to nearly one. Conditional volatilities $(\sqrt{h_t})$ of the long-short portfolio returns are plotted in Figure 2 for Amsterdam/London. Several features of these plots are noteworthy. First, it is clear that noise trader risk is significant and time-varying. During the sample period, conditional volatilities range from under 0.4% per day to over 1.6% per day for both long-short portfolios. Second, the plots for Royal Dutch/Shell and Unilever NV/PLC are remarkably similar. The sample correlation between the two conditional volatility series is 0.775. In both plots, conditional volatility increases dramatically between 1997 and 2000, and decreases thereafter. Periods of sustained high volatility are evident after August 1998 and again in early 2000. These periods coincide with the demise of LTCM and the peak of the internet/technology bubble, respectively.

That the volatility of noise trader risk varies considerably over time, and that there appears to be a common component in the volatility of noise trader risk, are new and striking results. It is important to emphasize that the graphs in Figure 2 plot the conditional volatility of the idiosyncratic component of hypothetical long-short portfolio returns. By assumption, fundamental risk is hedged out of the dependent variable $r_{A-B,t}$, and I attribute what remains to noise trading. The time-series regressions in equation (5) decompose this noise into systematic and idiosyncratic components. Thus, the graphs in Figure 2 plot the conditional volatility of idiosyncratic noise trader risk.

C New York Long-Short Portfolio Daily Returns

In this subsection, I analyze the risk of long-short portfolios formed in New York. Total returns for the twin stocks are computed from prices on New York shares (for Royal Dutch and Unilever NV) and ADRs (for Shell Transport and Unilever PLC). These total returns are obtained from CRSP. $r_{A-B,t}$ is the log total return on the Amsterdam-listed twin less the log total return on the London-listed twin. Sample standard deviations of New York long-short portfolio daily returns (reported in Table 1) are 0.89% per day for Royal Dutch/Shell and 0.71% per day for Unilever NV/PLC. These sample standard deviations are similar in magnitude to those reported for Amsterdam/London long-short portfolios.

For time-series regressions using New York long-short portfolio returns, only the return on the S&P 500 index is synchronized with the dependent variable. To account for non-synchronicity, I include the following day's observations for the independent variables measured in Europe. The New York specification is:

$$\begin{aligned} r_{A-B,t} \quad &= \quad \alpha + \phi r_{A-B,t-1} + \beta S\&P_t + \sum_{j=0}^{1} \delta_j FTSE_{t+j} + \sum_{k=0}^{1} \lambda_k AEX_{t+k} \\ &\quad + \sum_{l=0}^{1} \gamma_l \$/\pounds_{t+l} + \sum_{m=0}^{1} \nu_m \$/Fl._{t+m} + \varepsilon_t \end{aligned} \tag{7}$$

where $\$/Fl.$ is the log change in the dollar-to-guilder exchange rate and $\$/\pounds$ is the log change in the dollar-to-pound exchange rate. After adoption of the euro on January 1, 1999, $\$/Fl.$ is replaced by $\$/€$. All other independent variables are as defined for equation (5). I assume that the conditional variance of the residuals follows the GARCH(1,1) process described in equation (6).

If markets are frictionless and informationally efficient, then long-short portfolio returns should be unrelated to index returns and changes in exchange rates. This implies that the coefficients on the index returns and changes in exchange rates should be zero. Where lagged independent variables are included (e.g., $FTSE$), then the coefficients for that variable should sum to zero (e.g.,

$\delta_0 + \delta_1 = 0$). If arbitrage is limited, the habitat view of comovement predicts that long-short portfolio returns should be positively correlated with portfolios affected by noise trader risk in Amsterdam and New York (i.e., $\beta > 0$, $\delta > 0$, and $\gamma > 0$), and inversely correlated with portfolios affected by noise trader risk in London (i.e., $\lambda < 0$ and $\nu < 0$).

Panel B of Table 4 reports New York time-series regression results for Royal Dutch/Shell Transport and Unilever NV/PLC. Again, the results are similar for both pairs of twins, so I discuss them together. I first note that the adjusted R^2 statistics are lower for the New York regressions than for the Amsterdam/London regressions. The adjusted sample R^2 statistics for Royal Dutch/Shell and Unilever NV/PLC are 28.0% and 24.3% for the Amsterdam/London regressions, but only 13.7% and 12.1% for the New York regressions. Long-short portfolio returns are positively related to log changes in the AEX index (measured in guilders or euros) and the dollar-to-guilder or dollar-to-euro exchange rate, and negatively related to log changes in the FTSE 100 index (measured in pounds) and the dollar-to-pound exchange rate. Note that log returns (in dollars) on foreign indices can be decomposed into log returns (in the local currency) and log changes in the dollar-to-local currency exchange rate. Long-short portfolio returns are thus related to dollar returns of the equity indices of the markets where the twin stocks are traded most actively. These results are consistent with the habitat view of comovement. I also find that long-short portfolio returns measured in New York are strongly related to the S&P 500 index. If the constituent stocks of the S&P 500 are the habitat for a distinct group of noise traders, then this result is consistent with the habitat view of comovement as well. The coefficients on the lagged dependent variable are negative and significant. This is consistent with either fundamental or noise shocks being impounded in twin stock prices at different rates. Overall, these results are consistent with Froot and Perold (1996).[10] I reject the null hypothesis of frictionless and informationally efficient markets for both pairs of twins.

Similar results are reported in the literature on closed-end funds. Pontiff (1996) finds that closed-end fund discounts are related to the costs of arbitrage. Lee, Shleifer, and Thaler (1991) examine the proposition that fluctuations in the discounts on closed-end funds are related to changes in the sentiment of individual investors.[11] Their analysis hinges on two assumptions: (1) arbitrage is costly, and (2) individual investors are the dominant clientele for both closed-end funds and small-

[10]Froot and Perold (1996) report time-series regression results for New York-measured relative returns for Royal Dutch/Shell Transport. These results do not appear in Froot and Dabora (1999), which reports results for relative returns measured in Europe.

[11]Changes in closed-end fund discounts are analogous to the returns on a portfolio that is long the closed-end fund and short the constituent stocks.

cap stocks, but not for the stocks held by closed-end funds. In the habitat view of comovement, relative changes in the sentiment of individual investors relative to the sentiment of the broader market cause fluctuations in the discounts on closed-end funds. Consistent with this view, Lee, Shleifer, and Thaler (1991) find that changes in closed-end fund discounts are correlated with the returns of small-cap stocks. Further empirical support for this view is provided by Gemmill and Thomas (2002), who find that retail-investor flows, a proxy for individual investor noise trader sentiment, are related to fluctuations in closed-end fund discounts.

Estimates of the GARCH(1,1) parameters are also very similar to those reported for Amsterdam/London. Estimates of the persistence parameter a range from 0.941 to 0.954, and the sum $a+b$ is close to one for each regression. Conditional volatilities ($\sqrt{h}$) for the New York time-series regressions are plotted in Figure 3. As in Amsterdam/London, it clear that noise trader risk varies over time. For both long-short portfolios, conditional volatility jumps to over 1.4% per day around the failure of LTCM in 1998. Conditional volatilities are also high during the collapse of the internet/technology bubble in 2001. The increased volatility associated with the deletion of Royal Dutch and Unilever NV from the S&P 500 index in July 2002 is more pronounced in the New York regressions than in the Amsterdam/London regressions. The sample correlation between the two conditional volatility series is 0.413 for the New York time-series regressions.

D Long-Short Portfolio Weekly and Monthly Returns

The results reported thus far suggest that noise traders contribute significantly to daily long-short portfolio volatility. However, as discussed in Section 3, the volatility of daily long-short portfolio returns includes components related to microstructure-induced noise. These include noise due to the trading mechanism (e.g., bid-ask bounce, price discreteness) and noise due to differences in the rate at which private information is impounded into stock prices.

If microstructure-induced noise shocks are transient in nature, they should be relatively less important for longer horizon returns. To check the robustness of the results based on daily returns, I repeat the analysis of subsections 4.B and 4.C using weekly and monthly returns on long-short portfolios.

For weekly/monthly long-short portfolio returns, the specification for Amsterdam/London is

$$r_{A-B,t} = \alpha + \phi r_{A-B,t-1} + \beta S\&P_t + \delta FTSE_t + \lambda AEX_t + \gamma Fl./\$_t + \nu Fl./£_t + \varepsilon_t, \qquad (8)$$

and the specification for New York is

$$r_{A-B,t} = \alpha + \phi r_{A-B,t-1} + \beta S\&P_t + \delta FTSE_t + \lambda AEX_t + \gamma \$/£_t + \nu \$/Fl._t + \varepsilon_t. \tag{9}$$

I assume that conditional variance follows the GARCH(1,1) process described in equation (6).

Weekly returns are measured from Wednesday close to Wednesday close. For the Amsterdam/London model, $S\&P_t$ is measured from Tuesday close to Wednesday close to account for non-synchronous trading. For the New York model, the European index returns and log changes in exchange rates are measured from Wednesday close to Thursday close for the same reason. These adjustments are equivalent to including lagged variables in equation (5) or lead variables in equation (7). Monthly returns are measured in the conventional manner (month-end to month-end) with no adjustment for non-synchronous trading. The data are described in detail in sections 4.B and 4.C.

Panels A and B of Table 5 report weekly time-series regression results for Amsterdam/London and New York. The weekly results are very similar to the daily results reported in Table 4. Consistent with the habitat view, there is strong evidence that weekly long-short portfolio returns covary excessively with the stock market indices and currencies of the markets where the twin stocks trade most actively. The coefficients on the lagged long-short portfolio return are negative and significant. This is consistent with information being impounded into twin stock prices at different rates in different markets. GARCH effects are strong for weekly returns. As with daily returns, conditional volatility varies substantially over time. In Amsterdam/London, idiosyncratic noise trader risk ($\sqrt{h_t}$) ranges from 0.5% to 2.75% per week for Royal Dutch/Shell and 1.0% to 2.0% per week for Unilever NV/PLC.

Panels C and D of Table 5 report results for monthly long-short portfolio returns. The results are similar to the daily and weekly results with only one exception: I don't find evidence of GARCH effects in monthly returns for Unilever NV/PLC. Given that estimates of volatility are improved by using higher frequency data, this doesn't alter my conclusion that noise trader risk varies significantly over time.

Overall, the weekly and monthly regression results suggest that noise trading contributes significantly to the volatility of long-short portfolio returns.

5 Trading Costs

In addition to the risks discussed in the previous sections, arbitrageurs trading to profit from relative mispricings of twin stocks also bear trading costs. These trading costs include transaction costs and financing costs.

Transaction costs are incurred when positions are established or unwound. These costs include the bid-ask spread for both stocks and foreign exchange, transaction fees, transaction taxes,[12] and market impact costs. Transaction costs for large, liquid stocks such as the twins are not likely to explain the magnitude of the deviations from parity evident in Figure 1.

Arbitrageurs also incur financing costs to maintain long-short portfolios. Self-financing, costless arbitrage of the type envisioned in Scholes (1972) is available only in theory. Yet, modern hedge funds are capable of establishing large notional long-short positions with relatively little capital.[13] Long positions can be financed with as little as 2% cash margin (marked to market and settled daily) if the shares are posted as collateral. The financing cost is typically a small fee or spread added to the prevailing overnight interest rate (e.g., the Fed Funds rate). Short positions can be established by borrowing stocks in the equity lending market. D'Avolio (2002) and Geczy, Musto, and Reed (2002) describe institutional details of the equity lending market in the United States. In a typical transaction, the borrower posts cash collateral equal to 102% of the market value of the borrowed shares (i.e., the cash proceeds of the short sale plus a 2% "haircut"). Like the margin posted for the long leg of the trade, the collateral is marked to market and settled daily. The borrower receives daily interest equal to the "rebate rate" on the cash collateral. The rebate rate is less than the prevailing overnight interest rate. The difference is essentially the fee for borrowing the shares. When a stock is readily available for lending, it is known as "general collateral" (or GC) and fees for borrowing shares are relatively low. Geczy, Musto, and Reed (2002) report that fees for GC loans are typically 8 basis points per annum (bp) for large-size loans and 15 bp for medium-size loans. When a stock is scarce (i.e., "special"), borrowing shares can command a much higher fee (i.e., lower rebate rate). D'Avolio (2002) reports that the fee for borrowing shares and

[12]The United Kingdom levies a Stamp Duty (or Stamp Duty Reserve Tax (SDRT) for paperless transactions) of 0.50% on all stock exchange purchases. Prior to October 27, 1986, the Stamp Duty was 1.00%. Stock lending is exempt from the SDRT. Details of the U.K. Stamp Duty are provided in Inland Revenue (2003). The Netherlands does not have such a tax. In the United States, the tax is 1/300th of one percent.

[13]Federal Reserve Regulation T requires 50% margin for transactions with U.S. broker-dealers. In practice, Reg. T is not binding since borrowing/lending transactions are typically booked with offshore banks or offshore subsidiaries of U.S. banks.

the probability of being "special" are inversely related to market capitalization and institutional ownership. D'Avolio (2002, p. 273) concludes that "S&P 500 constituents, provided in excess supply by indexing lenders, are almost always general collateral."[14] For most of the sample period, the relatively overpriced stocks (i.e., Royal Dutch and Unilever NV) were constituents of the S&P 500. From this fact and the large shareholdings of these stocks in the United States, I infer that these stocks were easy to borrow and cheap to short for sophisticated institutional investors such as hedge funds.

Financing costs can be reduced somewhat by dividends when twin stocks are mispriced relative to one another. For example, assume that Royal Dutch is trading at a 10% premium relative to Shell Transport. If the dividend yield is 3% per annum, then a long-short relative value trade would provide positive carry of approximately 30 bp per annum.

6 Long-Term Capital Management

It is well-known that hedge funds and investment banks engage in "pairs trading" to profit from apparent violations of the law of one price. The most publicized case is that of Long-Term Capital Management (LTCM). LTCM's trading in the Royal Dutch/Shell pair is used as an illustrative example in Lowenstein (2000) and Dunbar (2000). Lowenstein (2000) reports (p. 99) that "Long-Term bet $2.3 billion—half of it long on Shell, the other half short on Royal Dutch—without, of course, any assurance that the spread would contract." Lowenstein continues (p. 100):

> "It was ridiculously big," said an executive at a Wall Street bank. Goldman Sachs had the same trade on. They believed it was a good trade. But Long-Term's trade was ten times the size of Goldman's.

[14]Table 4 in D'Avolio (2002) provides a list of the most expensive stocks to short for the April 2000 to September 2001 sample period. The appearance of Royal Dutch and Unilever NV ADRs on that list has led some to mistakenly believe that these stocks are, in general, expensive to short. However, there is a rational explanation. The high rebate rates reported in D'Avolio (2002) appear to be isolated incidents associated with tax motivated ex-dividend day trading. The two instances of high rebate rates (May 2001 for Unilever NV and August 2001 for Royal Dutch) occur in months in which those stocks went ex-dividend. The Netherlands imposes a withholding tax of 15% on dividends. So, the holder of a Dutch ADR receives only 85% of the dividend amount. Individuals and corporations (including securities dealers) in the U.S. can claim a foreign tax credit for this withholding. Tax-exempt investors such as pension funds can apply to have the 15% withholding refunded by the Netherlands. Mutual funds, however, can neither claim the tax credit nor apply for a refund. This means that mutual funds, and S&P 500 index funds in particular, had a strong incentive to participate in tax arbitrage schemes to recapture some of this withholding for their shareholders. They can do this by lending the Dutch ADRs to an arbitrageur, who in turn sells them to an investor who can either claim the foreign tax credit or apply for a tax refund. It is likely that the high rebate rates on ex-dividend days reflect the share of the arbitrage proceeds being paid to the index fund (and its custodian bank) as a fee. Cross-border tax arbitrage schemes of this sort are described by Callaghan and Barry (2003).

The market capitalization of Shell Transport on December 31, 1997 was approximately $7.2 billion. Since 96% of the Shell Transport's shareholdings were in the United Kingdom at the time, a long position of the magnitude attributed to LTCM must have been established in London.[15]

After staggering losses in August and September 1998, Federal Reserve Bank of New York President William J. McDonough orchestrated a takeover/recapitalization of LTCM by fourteen banks. After over a week of negotiation, the deal closed on the evening of Monday, September 28, 1998. Lowenstein (2000, p. 221) writes that, "In the wake of the rescue ... the spread on Royal Dutch/Shell—8 percent when Long-Term had entered the trade—ballooned to 22 percent." Figures 1, 2 and 3 indicate that both mispricing and noise trader risk increased sharply for both Royal Dutch/Shell and Unilever NV/PLC in 1998. Lowenstein (2000, p. 234) claims that LTCM lost $286 million on equity pairs trading between January 1, 1998 and the bailout. These losses are consistent with the increases in relative mispricing documented in Figure 1 for this period.

7 Conclusions

This paper provides new evidence regarding the magnitude and nature of noise trader risk. I study the returns for two pairs of "Siamese twin" stocks: Royal Dutch/Shell and Unilever NV/PLC. These twin stocks are exposed to the same fundamental risk factors and should respond identically to news about intrinsic value. Thus, they present a unique opportunity to learn about noise trader risk.

I examine two facets of noise trader risk: (1) the fraction of total return variation unexplained by fundamentals (i.e., noise), and (2) the short-run risk borne by arbitrageurs engaged in long-short pairs trading. In simple regressions of stock returns on the returns of a twin stock, I find that about 70% of daily return variation is explained by fundamentals. I attribute the remaining 30% to noise. The explained variation climbs to about 90% for monthly returns. The explained variation from this model-free approach greatly surpasses that reported by Cutler, Poterba, and Summers (1989), Roll (1988) and Fama (1990). However, I conclude that noise trading contributes substantially to daily return variation.

The relative mispricings between "Siamese twin" stocks are often cited as a puzzling violation

[15] Alternatively, the position could also be established through a total return swap (see Froot and Perold (1996)). However, the counterparty would likely hedge the long leg of the swap with a long position in Shell Transport in London. The effect would be the same.

of the law of one price and a challenge to the efficient markets hypothesis. I find that the significant and persistent deviations from theoretical parity previously documented by Rosenthal and Young (1990) and Froot and Dabora (1999) persisted and even increased in the 1990s despite the trading activity of well-capitalized hedge funds such as LTCM. Long-short arbitrage positions in these "Siamese twin" stocks are free of bad-model risk and fundamental risk. However, they are exposed to noise trader risk, and analysis of hypothetical long-short portfolio returns yields valuable insights into the nature of noise trader risk. Using a limited arbitrage-noise trader model of stock returns, I show that long-short portfolio returns reflect relative changes in noise trader sentiment across habitats. I find evidence that noise trader risk faced by arbitrageurs is substantial, that it has both systematic and firm-specific components, and that it varies considerably over time. As in Froot and Dabora (1999), I find that long-short portfolio returns covary excessively with the stock market indices and currencies of the markets where the twin stocks are traded most actively. The limited arbitrage-noise trader model attributes these correlations to comovements in noise shocks, not comovements in fundamental shocks. I find that the volatility of noise shocks is substantial and highly persistent. The level of noise trader risk varied from 0.4% to 1.6% per day over the sample period. Noise trader risk was especially high during the failure of LTCM in 1998 and peaked at the height of the internet/technology bubble in 2000. Since transaction and financing costs are relatively low for large, liquid stocks like the twins, it is likely that noise trader risk is a significant limit to arbitrage. This view is consistent with Pontiff (2006), who suggests that idiosyncratic risk is the single largest cost faced by arbitrageurs.

These results raise important questions about the broader issue of market efficiency. If noise trader risk can prevent arbitrageurs from eliminating relative mispricing between pairs of nearly identical assets, then what effect does noise trader risk have on absolute mispricings? The EMH relies on arbitrageurs to enforce an equilibrium in which prices, on average, reflect fundamental value. How efficient can financial markets be if, as Shleifer and Vishny (1990) predict, arbitrageurs are unwilling to commit capital to long-term assets?

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Table 1
Twin Stock and Long-Short Portfolio Risk

This table reports summary statistics describing the risk of individual stocks and long-short portfolios. Sample statistics include sample standard deviations (SD), first-order autocorrelation coefficients (ρ_1), and sample correlations (Corr.) between the log returns of twin stocks.

Panel A: Daily Returns

	Amsterdam/London Jan. 3, 1989 - Mar. 5, 2004 (3782 obs.)			New York Jan. 4, 1989 - Dec. 30, 2003 (3782 obs.)		
Return	SD	ρ_1	Corr.	SD	ρ_1	Corr.
RD	0.0147	0.013		0.0148	-0.070	
SC	0.0156	0.037		0.0149	-0.008	
RD-SC	0.0088	-0.230	0.833	0.0071	-0.275	0.884
RD-SC-Fl./£	0.0086	-0.305	0.841	n/a	n/a	n/a
UN	0.0147	0.053		0.0152	0.004	
UL	0.0155	0.058		0.0155	0.009	
UN-UL	0.0093	-0.213	0.810	0.0089	-0.279	0.830
UN-UL-Fl./£	0.0091	-0.258	0.821	n/a	n/a	n/a

Panel B: Weekly Returns, Jan. 1989 - Dec. 2003 (782 obs.)

	Amsterdam/London			New York		
Return	SD	ρ_1	Corr.	SD	ρ_1	Corr.
RD	0.0307	-0.117		0.0279	-0.082	
SC	0.0330	-0.131		0.0303	-0.102	
RD-SC	0.0151	-0.142	0.890	0.0108	-0.211	0.934
RD-SC-Fl./£	0.0132	-0.238	0.916	n/a	n/a	n/a
UN	0.0321	-0.056		0.0315	-0.012	
UL	0.0357	-0.073		0.0329	0.001	
UN-UL	0.0165	-0.160	0.887	0.0133	-0.255	0.916
UN-UL-Fl./£	0.0145	-0.220	0.913	n/a	n/a	n/a

Panel C: Monthly Returns, Jan. 1989 - Dec. 2003 (180 obs.)

	Amsterdam/London			New York		
Return	SD	ρ_1	Corr.	SD	ρ_1	Corr.
RD	0.0583	-0.001		0.0601	-0.139	
SC	0.0612	-0.117		0.0616	-0.136	
RD-SC	0.0285	-0.076	0.887	0.0202	-0.159	0.945
RD-SC-Fl./£	0.0228	-0.155	0.928	n/a	n/a	n/a
UN	0.0632	-0.060		0.0657	-0.075	
UL	0.0647	-0.066		0.0677	-0.041	
UN-UL	0.0283	-0.019	0.903	0.0247	-0.215	0.932
UN-UL-Fl./£	0.0228	-0.185	0.938	n/a	n/a	n/a

Table 2
Explained Variation in Daily Twin Stock Returns

This table reports regression estimates of the following model:

$$r_{A,t} = \alpha + \theta_{-1} r_{B,t-1} + \theta_0 r_{B,t} + \theta_1 r_{B,t+1} + \varepsilon_t$$

where $r_{A,t}$ and $r_{B,t}$ are log total returns for pairs of twin stocks. For Amsterdam/London returns, the Amsterdam-listed stock's return is converted to pounds sterling by subtracting the log change in the guilder-to-pound (or euro-to-pound) exchange rate. ^{a}, ^{b} and ^{c} denote significance at the 10%, 5% and 1% levels, respectively. Heteroskedasticity-consistent standard errors are reported in parentheses. DW: Durbin-Watson statistic, SEE: standard error of the estimate.

Panel A: Amsterdam/London Daily Returns, Jan. 3, 1989 - Mar. 5, 2004 (3782 obs.)

r_A	r_B	θ_{-1}	θ_0	θ_1	$p(\Sigma\theta_i = 1)$	$\overline{R}^2$	DW	SEE
RD-Fl./£	*SC*		0.784^c		0.000	0.707	2.59	0.0079
			(0.012)					
RD-Fl./£	*SC*	0.018^a	0.781^c	0.070^c	0.000	0.713	2.60	0.0078
		(0.010)	(0.012)	(0.011)				
SC	*RD-Fl./£*		0.902^c		0.000	0.707	2.55	0.0085
			(0.013)					
SC	*RD-Fl./£*	0.102^c	0.900^c	0.042^c	0.037	0.717	2.55	0.0083
		(0.012)	(0.013)	(0.012)				
UN-Fl./£	*UL*		0.787^c		0.000	0.674	2.44	0.0085
			(0.014)					
UN-Fl./£	*UL*	0.047^c	0.780^c	0.073^c	0.000	0.682	2.45	0.0084
		(0.012)	(0.014)	(0.011)				
UL	*UN-Fl./£*		0.856^c		0.000	0.674	2.46	0.0088
			(0.017)					
UL	*UN-Fl./£*	0.071^c	0.848^c	0.042^c	0.076	0.680	2.48	0.0088
		(0.012)	(0.017)	(0.012)				

Panel B: New York Daily Returns, Jan. 4, 1989 - Dec. 30, 2003 (3782 obs.)

r_A	r_B	θ_{-1}	θ_0	θ_1	$p(\Sigma\theta_i = 1)$	$\overline{R}^2$	DW	SEE
RD	*SC*		0.880^c		0.000	0.782	2.59	0.0069
			(0.011)					
RD	*SC*	0.012	0.880^c	-0.012	0.000	0.782	2.59	0.0069
		(0.010)	(0.011)	(0.010)				
SC	*RD*		0.889^c		0.000	0.782	2.46	0.0069
			(0.011)					
SC	*RD*	0.044^c	0.897^c	0.068^c	0.601	0.788	2.48	0.0068
		(0.009)	(0.011)	(0.010)				
UN	*UL*		0.812^c		0.000	0.688	2.51	0.0085
			(0.013)					
UN	*UL*	0.053^c	0.811^c	0.039^c	0.000	0.693	2.52	0.0084
		(0.011)	(0.013)	(0.011)				
UL	*UN*		0.848^c		0.000	0.688	2.50	0.0086
			(0.011)					
UL	*UN*	0.046^c	0.847^c	0.060^c	0.024	0.694	2.51	0.0086
		(0.012)	(0.016)	(0.012)				

Table 3
Explained Variation in Monthly Twin Stock Returns

This table reports regression estimates of the following model:

$$r_{A,t} = \alpha + \theta_0 r_{B,t} + \varepsilon_t$$

where $r_{A,t}$ and $r_{B,t}$ are log total returns for pairs of twin stocks. For Amsterdam/London returns, the Amsterdam-listed stock's return is converted to pounds sterling by subtracting the log change in the guilder-to-pound (or euro-to-pound) exchange rate. ^{a}, ^{b} and ^{c} denote significance at the 10%, 5% and 1% levels, respectively. Heteroskedasticity-consistent standard errors are reported in parentheses. DW: Durbin-Watson statistic, SEE: standard error of the estimate.

Panel A: Amsterdam/London Weekly Returns, Jan. 1989 - Dec. 2003 (782 obs.)

r_A	r_B	θ_0	$p(\theta_0 = 1)$	$\overline{R}^2$	DW	SEE
RD-Fl./£	*SC*	0.839^c	0.000	0.839	2.41	0.0121
		(0.017)				
SC	*RD-Fl./£*	1.000^c	0.975	0.839	2.48	0.0132
		(0.019)				
UN-Fl./£	*UL*	0.845^c	0.000	0.834	2.41	0.0134
		(0.017)				
UL	*UN-Fl./£*	0.988^c	0.363	0.834	2.44	0.0145
		(0.020)				

Panel B: New York Weekly Returns, Jan. 1989 - Dec. 2003 (782 obs.)

r_A	r_B	θ_0	$p(\theta_0 = 1)$	$\overline{R}^2$	DW	SEE
RD	*SC*	0.860^c	0.000	0.872	2.38	0.0100
		(0.013)				
SC	*RD*	1.013^c	0.440	0.872	2.42	0.0108
		(0.017)				
UN	*UL*	0.875^c	0.000	0.839	2.50	0.0126
		(0.015)				
UL	*UN*	0.959^c	0.000	0.839	2.48	0.0132
		(0.019)				

Panel C: Amsterdam/London Monthly Returns, Jan. 1989 - Dec. 2003 (180 obs.)

r_A	r_B	θ_0	$p(\theta_0 = 1)$	$\overline{R}^2$	DW	SEE
RD-Fl./£	*SC*	0.878^c	0.001	0.861	2.23	0.0216
		(0.036)				
SC	*RD-Fl./£*	0.981^c	0.688	0.861	2.25	0.0228
		(0.046)				
UN-Fl./£	*UL*	0.946^c	0.077	0.880	2.33	0.0226
		(0.031)				
UL	*UN-Fl./£*	0.931^c	0.050	0.880	2.26	0.0224
		(0.035)				

Panel D: New York Monthly Returns, Jan. 1989 - Dec. 2003 (180 obs.)

r_A	r_B	θ_0	$p(\theta_0 = 1)$	$\overline{R}^2$	DW	SEE
RD	*SC*	0.921^c	0.024	0.892	2.28	0.0197
		(0.035)				
SC	*RD*	0.970^c	0.497	0.892	2.26	0.0202
		(0.043)				
UN	*UL*	0.904^c	0.001	0.868	2.44	0.0239
		(0.030)				
UL	*UN*	0.961^c	0.319	0.868	2.36	0.0246
		(0.039)				

Table 4
Long-Short Portfolio Daily Time-Series Regressions
with GARCH(1,1) Conditional Variances

This table reports regression estimates of the Amsterdam/London model,

$$r_{A-B,t} = \alpha + \phi r_{A-B,t-1} + \sum_{i=-1}^{0} \beta_i S\&P_{t+i} + \delta FTSE_t + \lambda AEX_t + \gamma Fl./\$_t + \nu Fl./£_t + \varepsilon_t$$

and the New York model,

$$r_{A-B,t} = \alpha + \phi r_{A-B,t-1} + \beta S\&P_t + \sum_{j=0}^{1} \delta_j FTSE_{t+j} + \sum_{k=0}^{1} \lambda_k AEX_{t+k} + \sum_{l=0}^{1} \gamma_l \$/£_{t+l} + \sum_{m=0}^{1} \nu_m \$/Fl._{t+m} + \varepsilon_t$$

where $\varepsilon_t \sim \mathcal{N}(0, h_t)$ and the conditional variance h_t follows a GARCH(1,1) process:

$$h_t = c + ah_{t-1} + b\varepsilon_{t-1}^2$$

$r_{A-B,t}$ is the log total return of the Amsterdam-listed stock less the log total return of the London-listed stock (expressed in a common currency), *S&P* is the log total return on the S&P 500 index, *FTSE* is the log total return on the FTSE index, *AEX* is the log total return on the AEX index, *Fl./\$* is the log change in the guilder-to-dollar exchange rate, *Fl./£* is the log change in the guilder-to-pound exchange rate, *\$/£* is the log change in the dollar-to-pound exchange rate, and *\$/Fl.* is the log change in the dollar-to-guilder exchange rate. After adoption of the euro on January 1, 1999, *Fl./\$*, *Fl./£* and *\$/Fl.* are replaced by €/\$, €/£ and \$/€, respectively. Where leads or lags of an independent variable are included, the sum of coefficients is reported. Heteroskedasticity-consistent standard errors are reported in parentheses. [a], [b] and [c] denote significance at the 10%, 5% and 1% levels, respectively.

Panel A: Amsterdam/London Daily Regressions, Jan. 4, 1989 - Mar. 5, 2004 (3781 obs.)

Dep. Var.	*Lag*	*S&P*	*FTSE*	*AEX*	*Fl./\$*	*Fl./£*	*a*	*b*	$\overline{R}^2$
RD-SC-Fl./£	-0.278[c]	0.072[c]	-0.424[c]	0.278[c]	0.094[c]	-0.477[c]	0.967[c]	0.031[c]	0.280
	(0.013)	(0.018)	(0.018)	(0.015)	(0.019)	(0.023)	(0.007)	(0.007)	
UN-UL-Fl./£	-0.228[c]	0.084[c]	-0.397[c]	0.281[c]	0.135[c]	-0.540[c]	0.953[c]	0.043[c]	0.243
	(0.015)	(0.019)	(0.018)	(0.015)	(0.020)	(0.026)	(0.008)	(0.008)	

Panel B: New York Daily Regressions, Jan. 5, 1989 - Dec. 30, 2003 (3781 obs.)

Dep. Var.	*Lag*	*S&P*	*FTSE*	*AEX*	*\$/£*	*\$/Fl.*	*a*	*b*	$\overline{R}^2$
RD-SC	-0.279[c]	0.116[c]	-0.200[c]	0.060[c]	-0.264[c]	0.151[c]	0.954[c]	0.038[c]	0.137
	(0.016)	(0.014)	(0.023)	(0.019)	(0.021)	(0.017)	(0.011)	(0.008)	
UN-UL	-0.279[c]	0.092[c]	-0.210[c]	0.121[c]	-0.258[c]	0.237[c]	0.941[c]	0.057[c]	0.121
	(0.015)	(0.014)	(0.026)	(0.018)	(0.041)	(0.039)	(0.018)	(0.016)	

Table 5
Long-Short Portfolio Weekly and Monthly Time-Series Regressions with GARCH(1,1) Conditional Variances

This table reports regression estimates of the Amsterdam/London model,

$$r_{A-B,t} = \alpha + \phi r_{A-B,t-1} + \beta S\&P_t + \delta FTSE_t + \lambda AEX_t + \gamma Fl./\$_t + \nu Fl./\pounds_t + \varepsilon_t$$

and the New York model,

$$r_{A-B,t} = \alpha + \phi r_{A-B,t-1} + \beta S\&P_t + \delta FTSE_t + \lambda AEX_t + \gamma \$/\pounds_t + \nu \$/Fl._t + \varepsilon_t$$

where $\varepsilon_t \sim \mathcal{N}(0, h_t)$ and the conditional variance h_t follows a GARCH(1,1) process:

$$h_t = c + a h_{t-1} + b\varepsilon_{t-1}^2$$

$r_{A-B,t}$ is the log total return of the Amsterdam-listed stock less the log total return of the London-listed stock (expressed in a common currency), $S\&P$ is the log total return on the S&P 500 index, $FTSE$ is the log total return on the FTSE index, AEX is the log total return on the AEX index, *Fl./\$* is the log change in the guilder-to-dollar exchange rate, *Fl./£* is the log change in the guilder-to-pound exchange rate, *\$/£* is the log change in the dollar-to-pound exchange rate, and *\$/Fl.* is the log change in the dollar-to-guilder exchange rate. After adoption of the euro on January 1, 1999, *Fl./\$*, *Fl./£* and *\$/Fl.* are replaced by *€/\$*, *€/£* and *\$/€*, respectively. Heteroskedasticity-consistent standard errors are reported in parentheses. ^{a}, ^{b} and ^{c} denote significance at the 10%, 5% and 1% levels, respectively.

Panel A: Amsterdam/London Weekly Regressions, Jan. 1989 - Dec. 2003 (780 obs.)

Dep. Var.	*Lag*	*S&P*	*FTSE*	*AEX*	*Fl./\$*	*Fl./£*	*a*	*b*	$\overline{R}^2$
RD-SC-Fl./£	-0.191^c	0.104^c	-0.285^c	0.104^c	0.124^c	-0.336^c	0.897^c	0.098^c	0.197
	(0.034)	(0.025)	(0.026)	(0.022)	(0.030)	(0.043)	(0.035)	(0.035)	
UN-UL-Fl./£	-0.212^c	0.108^c	-0.313^c	0.161^c	0.104^c	-0.371^c	0.930^c	0.050^c	0.190
	(0.039)	(0.030)	(0.033)	(0.022)	(0.036)	(0.051)	(0.066)	(0.039)	

Panel B: New York Weekly Regressions, Jan. 1989 - Dec. 2003 (780 obs.)

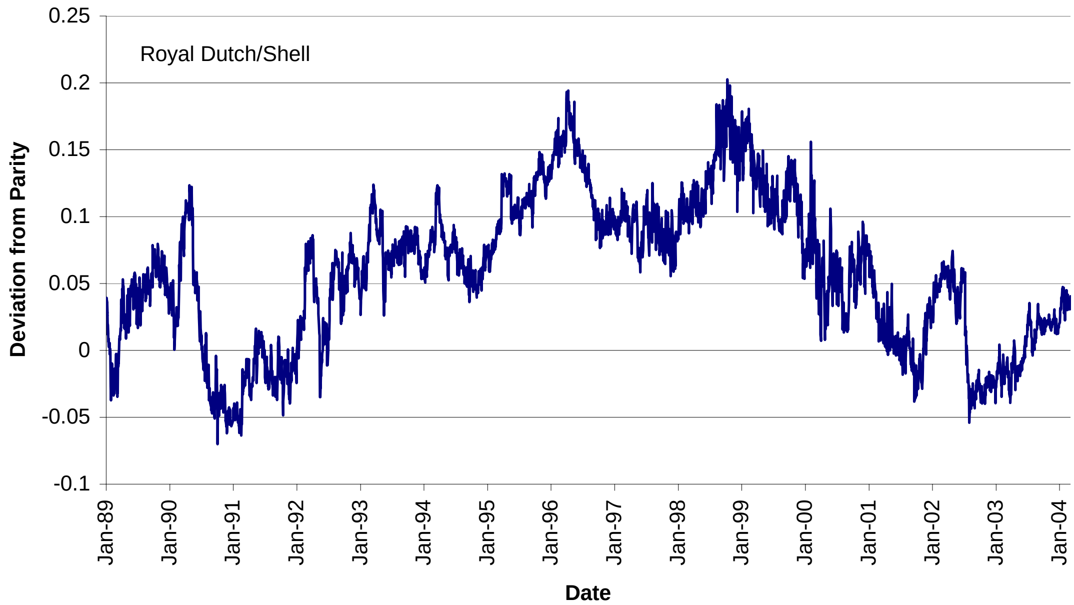
Dep. Var.	*Lag*	*S&P*	*FTSE*	*AEX*	*\$/£*	*\$/Fl.*	*a*	*b*	$\overline{R}^2$
RD-SC	-0.212^c	0.083^c	-0.169^c	0.041^b	-0.187^c	0.090^c	0.922^c	0.065^b	0.112
	(0.042)	(0.009)	(0.022)	(0.017)	(0.035)	(0.031)	(0.036)	(0.029)	
UN-UL	-0.246^c	0.072^b	-0.178^c	0.114^c	-0.203^c	0.165^c	0.854^c	0.095^b	0.128
	(0.035)	(0.030)	(0.030)	(0.021)	(0.037)	(0.033)	(0.079)	(0.045)	

Panel C: Amsterdam/London Monthly Regressions, Mar. 1989 - Dec. 2003 (178 obs.)

Dep. Var.	*Lag*	*S&P*	*FTSE*	*AEX*	*Fl./\$*	*Fl./£*	*a*	*b*	$\overline{R}^2$
RD-SC-Fl./£	-0.151^b	0.146^b	-0.369^c	0.174^c	0.176^c	-0.428^c	0.763^c	0.055	0.233
	(0.074)	(0.070)	(0.055)	(0.053)	(0.054)	(0.088)	(0.264)	(0.067)	
UN-UL-Fl./£	-0.173^b	0.159^b	-0.209^c	0.107^b	0.218^c	-0.421^c	0.007	0.211	0.164
	(0.078)	(0.063)	(0.047)	(0.044)	(0.055)	(0.066)	(0.124)	(0.355)	

Panel D: New York Monthly Regressions, Mar. 1989 - Dec. 2003 (178 obs.)

Dep. Var.	*Lag*	*S&P*	*FTSE*	*AEX*	*\$/£*	*\$/Fl.*	*a*	*b*	$\overline{R}^2$
RD-SC	-0.207^b	0.175^c	-0.263^c	0.117^b	-0.324^c	0.174^c	0.533^b	0.292	0.182
	(0.085)	(0.057)	(0.041)	(0.052)	(0.057)	(0.066)	(0.238)	(0.193)	
UN-UL	-0.216^c	0.073^a	-0.178^c	0.093^a	-0.315^c	0.107	-0.054	0.051	0.107
	(0.071)	(0.042)	(0.051)	(0.048)	(0.077)	(0.087)	(0.245)	(0.042)	



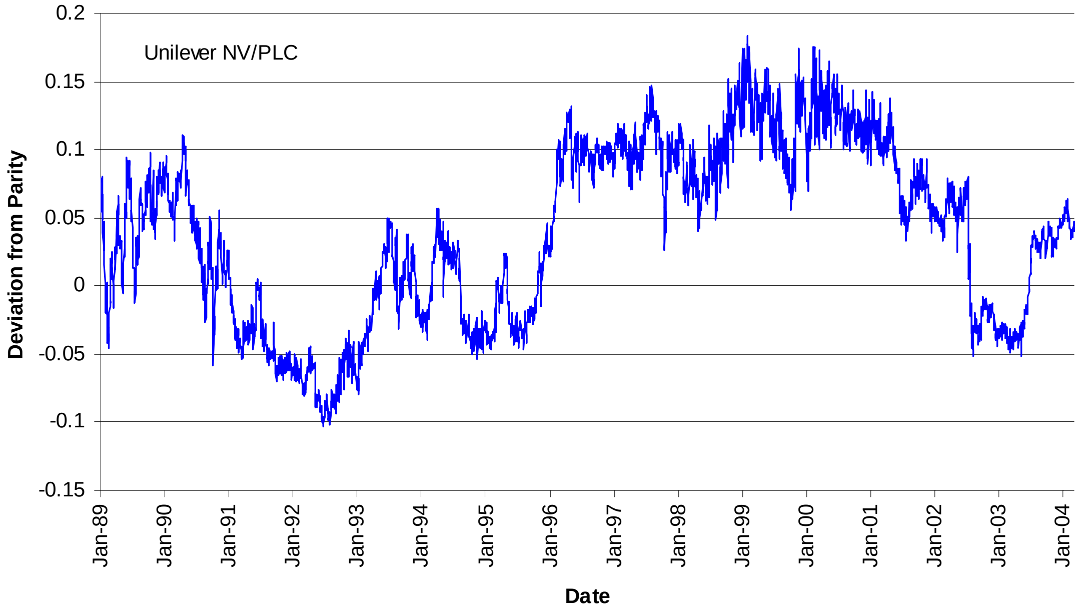


Figure 1: **Deviations from Theoretical Parity: Amsterdam/London.** Deviations from theoretical parity for Royal Dutch Petroleum vs. Shell Transport (top) and Unilever NV vs. Unilever PLC (bottom) for the period January 4, 1989 to March 5, 2004. Deviations are based on closing prices and foreign exchange rates in Amsterdam/London.

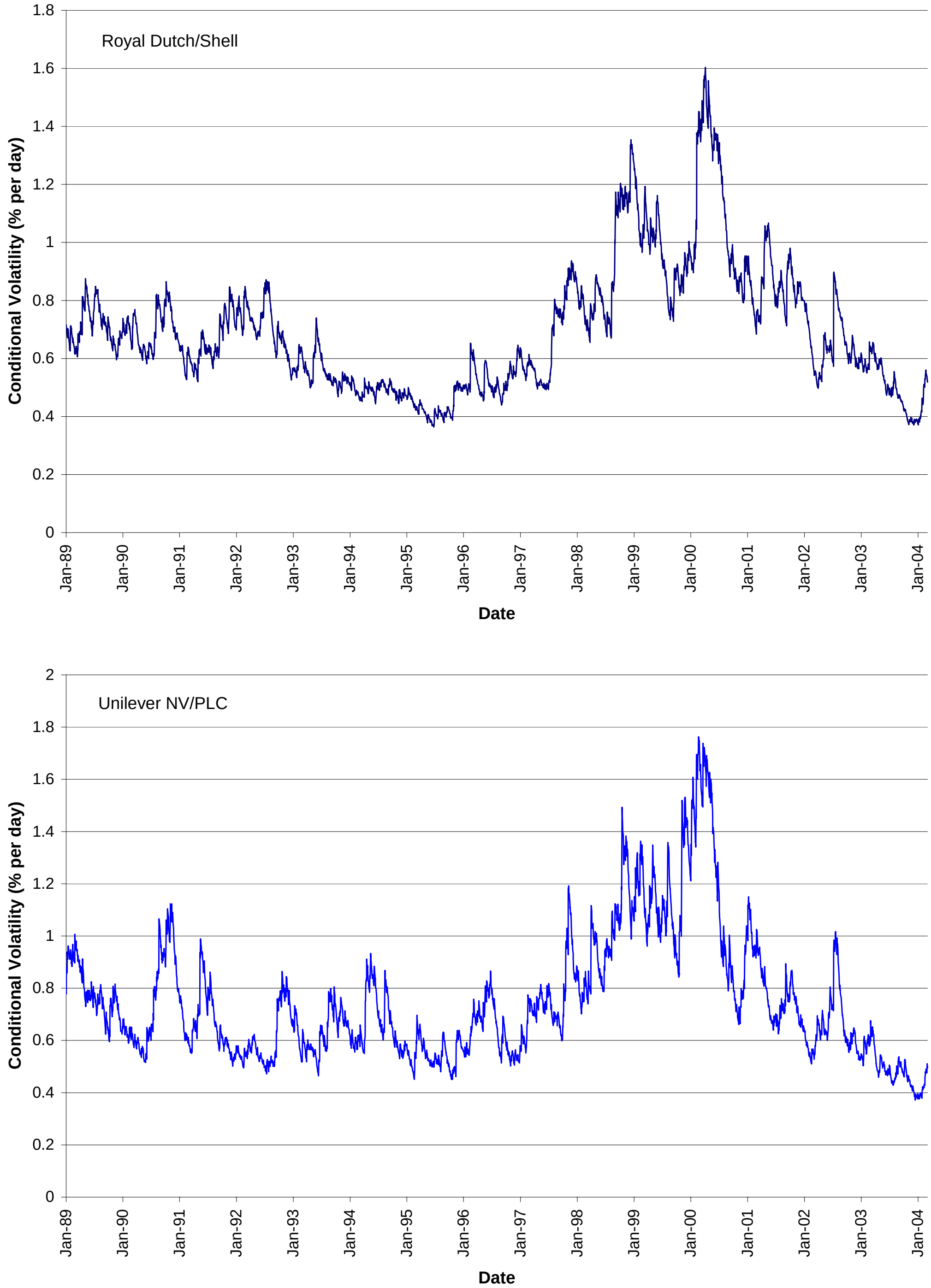
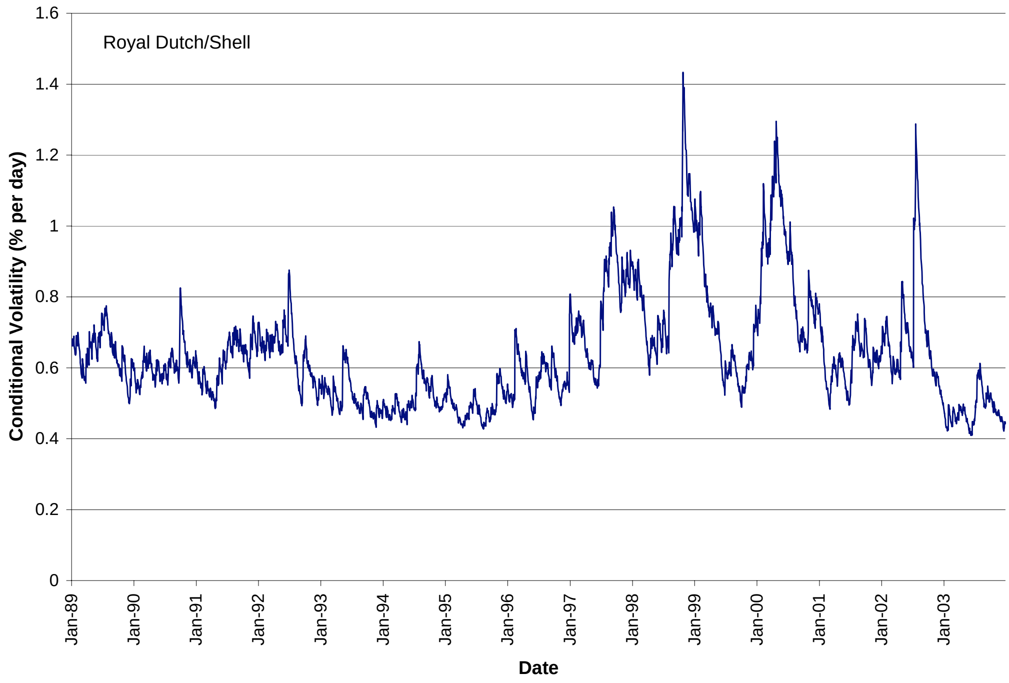


Figure 2: **Conditional Volatility of Noise Trader Risk: Amsterdam/London.** Time-series plots of conditional volatilities of noise trader risk in Amsterdam/London for Royal Dutch/Shell (top) and Unilever NV/PLC (bottom) for January 4, 1989 to March 5, 2004. The plotted values are square roots of fitted variances from a GARCH(1,1) process.



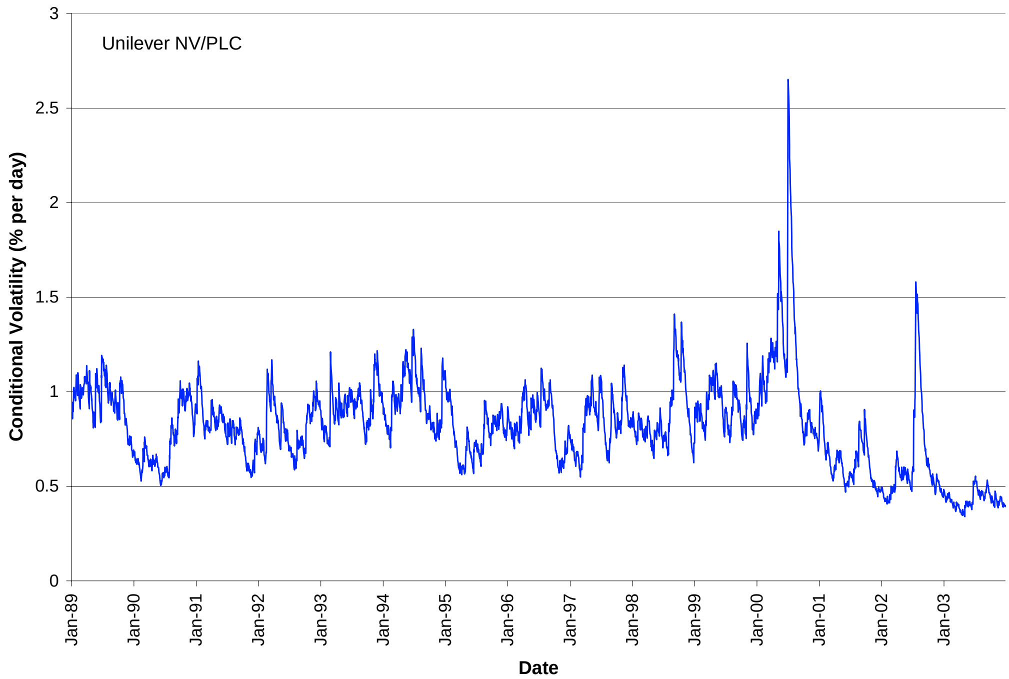


Figure 3: **Conditional Volatility of Noise Trader Risk: New York.** Time-series plots of conditional volatilities of noise trader risk in New York for Royal Dutch/Shell (top) and Unilever NV/PLC (bottom) for January 5, 1989 to December 30, 2003. The plotted values are square roots of fitted variances from a GARCH(1,1) process.