Efficiency Tests of the French Index (CAC 40) Options Market

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Abstract

This paper examines the efficiency of the French options market (MONEP) using transaction data on CAC 40 index options during the period January 02, 1997 through December 30, 1999. In terms of contract volume, CAC 40 options are the most heavily traded index options in the world. We test several no arbitrage conditions (lower boundary, put-call parity, box spread, call spread, put spread, call convexity and put convexity) taking transaction costs and short sale constraints into account. Overall, our results support efficiency of the MONEP as the frequency of arbitrage condition violation is low. However, the size of the profit potential for low cost institutional traders in some strategies is a concern. While the shift to the Euro and the associated changes in the option contract specification improved volume, we do not find any clear evidence of enhanced efficiency. There is some evidence that arbitrage condition violations coincide with brisk trading and exhibit systematic patterns opposite to those found in the US.

Keywords: market efficiency, index options, no arbitrage conditions.

JEL Classification: G13, G14.

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1. Introduction

Efficient financial markets are important for capital allocation, price discovery and risk management. Growth of the financial markets may also depend on whether the markets are operating efficiently. While efficiency of the mature and large financial markets naturally continues to draw significant attention from researchers, ironically it is the new and smaller markets that are more likely to lack efficiency. For one thing, the arbitrageurs whose profit seeking activities enforce proper alignment of the prices are not as numerous in the new and smaller markets as they are in the large and established markets.

The purpose of this paper is to empirically test the efficiency of a relatively new but important and growing market, namely the French options market MONEP (*Marché des Options Négociables de Paris*). More specifically, we study the efficiency of the market for options on the well-known French stock index CAC 40 (Compagnie des Agents de Change 40) using intra-day data during January 2, 1997 through December 30, 1999. Trading in CAC 40 options started in 1991. Since the switch to the Euro and the associated contract modifications in 1999, CAC 40 options have surpassed S&P 500 and DAX in terms of volume (number of contracts) and are now the most actively traded index options in the world.

Our paper joins the small body of research on options markets in continental Europe (Puttonen (1993, Finnish, Index), Lefoll (1994, Swiss, Equity), DeRoon, Veld and Wei (1995, Dutch, Equity), Berg, Brevik and Saettem (1996, Norwegian, Equity) and Cavallo and Mammola (2000, Italian, Index)). Given the popularity of CAC 40, our study provides potentially important evidence to the market participants in France and beyond. Further, the switch to Euro offers a valuable opportunity to understand how major structural changes affect the efficiency of derivatives markets.

In this paper, we accept the absence of arbitrage opportunities as the operational definition of market efficiency. One clear benefit of this definition is that our tests are not dependent on the validity of any option valuation model. We examine the validity of seven theoretical conditions on arbitrage-free pricing of options. The tests of lower boundary and put-call parity (PCP) provide evidence on the joint or cross-market efficiency of the underlying market for CAC 40 stocks and the index options. The tests involving call (put) spread and call (put) convexity are meant to test efficiency of the index call (put) options market alone while the box spread test allows us to test the relative pricing of index call and put options. Together the spread and convexity tests offer evidence regarding the internal efficiency of the index options market. One advantage of these internal efficiency tests is that the feasibility of arbitrage transactions using only options is better than when both options and the underlying asset(s) are used. This is specially so for index options where there is no tracking security for the index, which is the case in our sample.[1] Possibly stale nature of the index is not a factor either in spread tests.

A small group of previous studies (e.g., Galai (1979), Bhattacharya (1983), Billingsley and Chance (1985), Ronn and Ronn (1989), Ackert and Tian (1999, 2000)) tests options market efficiency using the spreads.[2] Using intra-day data and spreads should improve efficiency tests in smaller markets where the stock and option quotes are more likely to be non-synchronous and execution of inter-market arbitrage may be more time consuming and costly. We also take into account dividends on the underlying component stocks, transaction costs and short sale constraints. The CAC 40 options are European and hence our test results are not affected by the complications in arbitrage conditions that arise due to the early exercise feature of American options (Kamara and Miller (1995)).

In general, our empirical results for the CAC 40 index options are in line with previous findings for index options in the US (Evnine and Rudd (1985, US, S&P 100), Chance (1987, US, S&P 100), Kamara and Miller (1995, US, S&P 500), Ackert and Tian (1999, 2000, US, S&P 500)) and elsewhere (Ackert and Tian (1998, Canada, TIP 35), Puttonen (1993, Finland, FOX), Cavallo and Mammola (2000, Italy, MIB30)). Over the sample period January 1997 though December 1999, we find many violations of the arbitrage conditions as applied to the CAC 40 index and options. But the frequency of violations diminishes considerably as we factor in various market frictions (bid-ask spread, exchange fees, brokerage commissions, and short sale constraint). Therefore, considering the incidence of profitable arbitrage opportunities, our study supports the efficiency of the French index options market, the MONEP. In fact, the arbitrage

[1] A tracker (*Exchange Traded Fund*) on CAC 40 index, named Master Share CAC 40, was introduced on NextTrack, the Euronext market segment dedicated to trackers, on January 22, 2001. Euronext was created by the merger of the exchanges in Amsterdam, Brussels and Paris. With the completion of Euronext's planned integration process, it will be the first fully integrated, cross-border, European market for equities, bonds, derivatives and commodities. Euronext currently operates through Euronext Amsterdam, Euronext Brussels and Euronext Paris.

[2] An alternative approach (e.g., Black and Scholes (1972), Galai (1977), DeRoon, Veld and Wei (1995)) use hedge strategies to examine arbitrage opportunities. These strategies require positions in multiple options as the spreads do. However, the greek-neutral strategies are model dependent.

conditions involving options alone indicate a higher level of efficiency for the CAC 40 index options market compared to the S&P 500 index option market, the most mature and the largest (in terms of traded contract value) in the world.

However, the size of the profit potential for low cost institutional traders in some strategies indicate some inefficiency comparable to that found in Italy (Cavallo and Mammola (2000)), another relatively new European options market. While the shift to the Euro and the associated changes in the option contract specification improved volume significantly, we do not find any clear evidence of enhanced efficiency. In fact, efficiency seems to have diminished in some instances. There is also some evidence that arbitrage opportunities are more common during periods of brisk trading. However, we do not attempt to establish any causality in this regard. Lastly, we find that the systematic patterns of Put-Call Parity violations in the CAC 40 options market are different from those observed in the S&P 500 options market. This could be due to possible cultural/institutional differences between the two markets.

The remainder of this paper is organized as follows. In section 2, we discuss the arbitrage pricing relations under study. Section 3 describes the French institutional framework and the data that we use. The empirical results are presented in Section 4 and a summary of our findings and concluding comments follow in Section 5.

2. Arbitrage pricing relationships

There are three ways to test the efficiency of the options market. The first is to compare the actual market prices of options and the estimated option prices generated from a theoretical option pricing model.[3] A second approach consists in testing the profitability of a trading rule based on the time series predictability of implied volatility.[4] This approach has the advantage of

[3] For an analysis of the empirical performance of alternative option pricing models for the CAC 40 Index options, see Capelle-Blancard (2001). Early on, Black and Scholes (1972), Black (1975), Galai (1977), and Finnerty (1978) used the celebrated Black and Scholes (1973) option pricing model to identify mispriced equity options in the United States. For US index options, Evnine and Rudd (1985, S&P 500) and Cotner and Horrell (1989, S&P 100) find the constant variance Black-Scholes model to exhibit pricing biases that are in part explained by stochastic volatility models according to Sheikh (1991, S&P 100). Chance (1986, S&P 100) also concluded that the Black-Scholes model cannot be used to generate abnormal returns from trading index options. Galai (1983) surveys early studies on the Black-Scholes model and options market efficiency while Bates (1996) provides a recent survey that includes findings about more general option pricing models. Also, see Chaudhury (1985) for a critique of the empirical methods used in testing the validity of the Black-Scholes option pricing model.

[4] For evidence on US equity options, see, e.g., Latane and Rendleman (1976), Chiras and Manaster (1978), and Whaley (1982). For S&P 100 Index options, Day and Lewis (1992) find option prices to be informative about future

not requiring exogenous volatility forecasts of the underlying asset returns.[5] Such tests are, however, joint tests of the validity of the theoretical option pricing model, the level of synchronization between the spot and options markets and the efficiency of the options market. The third approach takes the stock and option market prices as given and simply looks at possible violations of no-arbitrage relationships among the prices. In this paper, we use this last approach.

The fundamental premise behind the no-arbitrage price relations is that investment strategies with identical future cash flows should be priced the same. The main advantage of the no-arbitrage approach to testing efficiency is that it does not rely on assumptions about traders' risk preferences and market price dynamics. Indeed, it only assumes that "free lunch" can not exist in efficient markets and investors prefer more to less. Since the no-arbitrage tests use only the observed market prices or quotes to initiate trades, the tests can be considered as tests of the weak form of market efficiency.

In the remainder of the paper, we will use the following notation:

C : price of a European call option;
P : price of a European put option;
S : price of the underlying asset;
K : strike price;
t : time to maturity of the option;
r : risk free rate of interest;
D: dividends paid on the CAC 40 index during the remaining life of the option, discounted at the risk free rate of interest;[6]
l : is the percent of proceeds available to CAC 40 short sellers in the stock market.[7]

The ask and bid prices of the securities are denoted by the superscripts a and b while t_i, $i = c, p, s, r$, represents the transaction costs other than the bid-ask spread for one-way trading of

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realized volatility while Canina and Figlewski (1993) find the opposite result. On the DAX market, Schmitt and Kaehler (1996) find that an autoregressive model for the implied volatility index (VDAX) generates lower profit than the historical volatility or the GARCH model from delta-neutral volatility trading.

[5] In a similar way, Poon and Pope (2000) suggest testing the joint efficiency of options written on financial assets that are close substitutes. Such tests do not require forecasts of volatility of the underlying asset returns since they focus on the relative pricing efficiency.

[6] We assume that traders have perfect knowledge about future dividend payments.

the call and put options, replicating the index and lending or borrowing at the risk-free rate respectively.

The remainder of this section describes the arbitrage conditions that we test in this paper. The lower boundary conditions (*1a* and *1b*) for the call and put options are in section 2.1, followed by the Put-Call Parity (*2a* and *2b*) in section 2.2. Thus the conditions in sections 2.1 and 2.2 concern arbitrage across the stock and the options markets and are intended to explore the relative efficiency of the options market. Arbitrage conditions involving options alone are described next. The call and put spread (*3a* and *3b*) conditions in section 2.3 and the call and put convexity (*5a* and *5b*) conditions in section 2.5 are meant to test the relative pricing efficiency of call options alone or put options alone. The box spread conditions (*4a* and *4b*) in section 2.4, on the other hand, enforce pricing efficiency across call and put options. We describe the box spread conditions immediately after the call and put spread conditions but before the convexity conditions as the box spreads combine the call and put spreads.

2.1 Call & Put Lower Boundary Conditions

To preclude arbitrage across the options market and their underlying asset market, the following inequalities must hold for every call and put option:

$$C^a + t_c - Max\left[\lambda(S^b - D) - K\exp(-r\tau) - (t_S + t_r), 0\right] \geq 0 \qquad (1a)$$

$$P^a + t_p - Max\left[K\exp(-r\tau) - (S^a - D) - (t_S + t_r), 0\right] \geq 0 \qquad (1b)$$

In essence, condition *(1a)* dictates that a call option must be worth at least its intrinsic value, namely the dividend adjusted price of the underlying asset net of the present value of the strike price for an in-the-money option, zero otherwise. In a similar fashion, condition *(1b)* dictates that a put option must be worth at least its intrinsic value, namely the present value of the strike price net of the dividend adjusted price of the underlying asset net for an in-the-money option, zero otherwise.

Suppose condition *(1a)* is violated. One can set up an arbitrage strategy of short selling the stock, using part of the proceeds to buy the call option and lending the present value of the

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[7] As in Kamara and Miller (1995), it represents the additional costs of short selling in the stock market. We assume also that there is no additional cost of short selling in the option market (Figlewski and Webb (1993)).

strike price (buying risk-free asset with face value K). This strategy would leave the arbitrageur with positive cashflow now and non-negative cashflow at maturity. If *(1b)* is violated, an arbitrageur would borrow the present value of the strike price and use part of the proceeds to buy the underlying asset and the put option. Therefore, if either *(1a)* or *(1b)* is violated, the options market is undervaluing the options relative to the value of the underlying asset.

2.2 Put-Call Parity (PCP)

The put-call parity was first established by Stoll (1969) and then extended and modified by Merton (1973a, 1973b).[8] When there are no dividend payments, transaction costs or short-selling constraints, the basic put-call parity condition is the following:

$$C + K\,exp(-rt) = P + S$$

If the PCP is violated, one can make risk-free arbitrage profit by pursuing a *long* or a *short* arbitrage strategy. The *short* strategy involves selling the put option and short selling the stock portfolio that replicates the index at their bid prices and simultaneously buying the call option at the ask price and lending at the risk-free rate. The *long* strategy involves buying the stock portfolio that replicates the index and the put option at their ask prices and simultaneously selling the call option at its bid price and borrowing at the risk-free rate. The name *short* or *long* means to indicate the arbitrage position in the underlying asset.

Considering transaction costs and short-selling restrictions, the PCP restrictions that prevent the profitability of the *short* and the *long* arbitrage strategies respectively are as follows:

$$[C^a + K\,exp(-rt)] - [P^b + l(S^b - D)] + (t_c + t_p + t_S + t_r) \geq 0 \qquad (2a)$$

$$[P^a + (S^a - D)] - [C^b + K\,exp(-rt)] + (t_c + t_p + t_S + t_r) \geq 0 \qquad (2b)$$

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8 Put-call parity is also used to proxy the implied index level or the risk free interest rate. For example, see Finucane (1991) who tests lead-lag relationships between the S&P 100 index and the OEX options by using the implied index level derived from the PCP relation. Shimko (1993) estimates the risk free interest rate from the PCP to recover the risk neutral probability density function.

If the inequality *(2a)* is violated, put option is overvalued relative to the call option given the value of the underlying stock index. Hence an arbitrageur can profit by pursuing the *short* strategy that involves selling the overvalued put option and simultaneously buying the undervalued call option. One can also think of this arbitrage as creating a synthetic *short* position in the risk-free asset and lending directly. This is because the *short* positions in the underlying asset and the put option combined with the *long* position in the call option leads to a terminal payoff of –K.

Similarly, if the inequality *(2b)* is violated, call option is overvalued relative to the put option given the value of the underlying stock index. Hence an arbitrageur can profit by pursuing the *long* strategy that involves selling the overvalued call option and simultaneously buying the undervalued put option. One can also think of this strategy as creating a synthetic *long* position in the risk-free asset and borrowing directly. This is because the *long* positions in the underlying asset and the put option combined with the *short* position in the call option leads to a terminal payoff of K.

As the underlying asset is an index, arbitrageurs however face several problems when they trade in the cash market. *First*, if some of the stocks in the index do not have liquidity and depth, it is often difficult to simultaneously buy or sell a stock portfolio replicating the index at a set of specified prices. *Second*, short selling of stocks is, in general, subject to many institutional restrictions. *Third*, dividends may affect arbitrage performance. Fourth, arbitrage operations may involve high trading costs.

Given that the index futures prices are related to their underlying cash index values *via* the cost of carry relationship, arbitrageurs might prefer to combine index futures with index options without taking any position in the cash index replicating portfolio. While a liquid index futures market should facilitate arbitrage, using futures instead of a stock portfolio replicating the index creates possible basis risk. A liquid tracking security, if it exists, should alleviate these problems and enhance efficiency (absence of inter-market arbitrage) as argued by Ackert and Tian (1998, 1999).

2.3 Call & Put Spreads

A call (put) spread is a combination of two calls (puts) with different strike prices but identical maturity. A bullish (bearish) call (put) spread involves purchasing (selling) a call (put) with strike price K_1 and simultaneously selling (purchasing) a call (put) with strike price K_2, where $K_1 < K_2$. The terminal payoff from the bullish (bearish) call (put) spread strategy is zero when the index is lower (higher) than $K_1(K_2)$, strictly positive otherwise. In the absence of arbitrage and when all transaction costs are taken into account, the following inequalities should hold:

$$(C_2^a - C_1^b) + (K_2 - K_1)\,exp(-r\tau) + (2t_c + t_r) \geq 0 \qquad (3a)$$

$$(P_1^a - P_2^b) + (K_2 - K_1)\,exp(-r\tau) + (2t_p + t_r) \geq 0 \qquad (3b)$$

Suppose the arbitrage condition *(3a)* is violated. It means that the lower strike (K_1) call option is overvalued relative to the higher strike (K_2) call option. An arbitrageur would then sell the bullish call spread, i.e., sell the overvalued lower strike call option and buy the undervalued higher strike call option and lend $(K_2 - K_1)\,exp(-r\tau)$. This would leave the arbitrageur with a positive cashflow (the remainder of net proceeds from options after lending) now and a non-negative cashflow at maturity. [9]

Now suppose the arbitrage condition *(3b)* is violated. It means that the higher strike (K_2) put option is overvalued relative to the lower strike (K_1) put option. An arbitrageur would then sell the bearish put spread, i.e., sell the overvalued higher strike put option and buy the undervalued lower strike put option and lend $(K_2 - K_1)\,exp(-r\tau)$. This would leave the arbitrageur with a positive cashflow (the remainder of net proceeds from options after lending) now and a non-negative cashflow at maturity.

2.4 Box Spreads

A box spread combines a bullish call spread and a bearish put spread. It create a risk-free position by purchasing call and put options with strike prices K_1 and K_2 respectively and selling call and put options with strike prices K_2 and K_1 respectively. The terminal payoff of this portfolio

[9] The maximum payment obligation of the arbitrageur at maturity due to selling the bullish call spread alone is $K_2 - K_1$. This happens when the terminal stock price is above the higher strike price K_2 and both options expire in-the-money. When the terminal stock price is below the lower strike price K_1 and both options expire out-of-the-money, the net options payment obligation for the arbitrageur is zero. In between, the net options payment obligation is the terminal stock price net of the lower strike price due to the option sold. This is, however, less than the difference between the two strike prices.

is equal to $K_2 - K_1$ whatever the index may be at maturity and is positive since $K_1 < K_2$. Accounting for all transaction costs involved, the following no arbitrage inequalities must hold:

$$(C_1^a - C_2^b) - (P_1^b - P_2^a) + (K_1 - K_2)\,exp(-r\,t) + (2t_c+2t_p+t_r) \geq 0 \qquad (4a)$$

$$(C_2^a - C_1^b) - (P_2^b - P_1^a) + (K_2 - K_1)\,exp(-r\,t) + (2t_c+2t_p+t_r) \geq 0 \qquad (4a)$$

The arbitrage inequality *(4a)* corresponds to buying a bullish call spread and a bearish put spread and borrowing the amount $(K_2 - K_1)exp(-r\,t)$. The total net cost of options including transaction costs is $(C_1^a - C_2^b) - (P_1^b - P_2^a) + (2t_c+2t_p)$. The net proceeds from borrowing is $(K_2 - K_1)\,exp(-r\,t) - t_r$.. Since the future payoff from options $(K_2 - K_1)$ is exactly the amount needed to pay off the loan, it is necessary to have the total net cost of options including transaction costs to be at least as high as the amount of borrowing net of the transaction cost. Otherwise, there is an arbitrage opportunity. The arbitrage inequality *(4b)* imposes a similar restriction on selling a bullish call spread and a bearish put spread and lending the amount $(K_2 - K_1)exp(-r\,t)$. Since the strategy in *(4a)* requires net investment for the options while *(4b)* generates net proceeds from options, we shall refer to *(4a)* as the *long* box spread and to *(4b)* as the *short* box spread.

2.5 Call & Put Convexities (Butterfly Spreads)

Call (put) convexity, also referred to as a butterfly spread, requires purchase of calls (puts) with strike prices K_1 and K_3, and sale of calls (puts) with strike price K_2 where $K_1 < K_2 < K_3$. The terminal payoff of this strategy is zero if the index is lower than K_1 or greater than K_3, strictly positive otherwise. The no arbitrage call and put convexity conditions, when transaction costs are taken into account, are expressed as:

$$wC_1^a + (1-w)C_3^a - C_2^b + 3t_c \geq 0 \qquad (5a)$$

$$wP_1^a + (1-w)P_3^a - P_2^b + 3t_p \geq 0 \qquad (5b)$$

with $w = (K_3 - K_2) / (K_3 - K_1)$. If the strikes are equally spaced (w=1/2), convexity involves purchasing one each of the two end strike options for every two middle strike options sold.

Suppose the arbitrage condition is *(5a)* violated. This means that the middle strike call option is overvalued relative to a portfolio of lower and higher strike call options. In other words, the observed option prices as a function of the strike price are not convex enough. Assuming

$w=1/2$, an arbitrageur would then sell two middle strike call options for every pair of end options bought. Beyond the end strike prices, the terminal payment obligation for the arbitrageur is nil. In between the end strikes, the arbitrageur would enjoy a positive payoff with the highest payoff occurring when the terminal asset price (index value) is equal to the middle strike.

3. The database and the transaction costs

Our study focuses on the CAC 40 index options (PXL contracts). The CAC 40 Index is calculated as the capitalization-weighted arithmetic average of the prices for the component stocks. [10] Some representative information about the components of the CAC 40 Index is presented in Appendix A. The index has a December 31, 1987 base value of 1,000 and the index value is disseminated every thirty seconds by *Euronext* Paris. As of September 20, 1999, France Telecom was the largest component of the CAC 40 Index and accounted for 10% of the index. Five other stocks (ELF Aquitaine, Total FINA, AXA, Vivendi, L'Oreal) had a weighting of more than 5% each and together with France Telecom accounted for about one-third of the CAC 40 index. As of August 31, 1999, the total market capitalization of the forty stocks in the CAC 40 Index was more than EUR 700 billion and they accounted for over 80% of trading volume on Premier Marché of *Euronext* Paris. The shares are traded in an order-driven market on a screen-based electronic system called NSC-SuperCAC.

Equity and index futures and options are traded on the *Marché des Options Négociables de Paris* (MONEP).[11] Since 1998, trading in CAC 40 index derivatives has become fully automated. Previously traded by a combined electronic/open outcry process, the option and future contracts were switched to NSC-VO (*version option*) and NSC-VF (*version future*) systems in March, 1998 and April, 1998 respectively. Unlike the stock market, the MONEP is a quote-driven market and there are designated market makers for actively traded derivatives, including the CAC 40 index options. However, there is no discrepancy between the stock and the options markets in terms of trading hours. The stock and options markets opened at 10:00 AM and closed at 17:00 PM during our sample period.[12]

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[10] The selection of CAC 40 component stocks is made in accordance with several requirements such as capitalization and liquidity.

[11] Interest rate and commodity contracts are traded on the *Marché à Terme International de France* (MATIF).

[12] Since April 2, 2000 markets open at 9:02 AM and close at 17:30 PM.

Trading in CAC 40 options started in 1991 and they are now the most popular options on the MONEP.[13] The exercise style of CAC 40 options is European, i.e., the options can be exercised only at maturity time. Some features of these option contracts have changed with the shift to the Euro. Before January 1999, options were available for two half-yearly expiration dates (March and September) and consecutive strike prices were separated by 150 index points. The contract size was FRF 50 times the CAC 40 index and the minimum price fluctuation, namely the tick size, was 0.01 index point. At expiration, the cash settlement was equal to the difference between the exercise price and the expiration settlement index times FRF 50.

Starting in January 1999, options are available for eight expiration dates (3 monthly, 3 quarterly and 2 half-yearly). The consecutive strike prices are now separated by 50 index points for monthly expirations, 100 index points for quarterly expirations and 200 index points for half-yearly expirations. The contract size has changed to EUR 1 times the CAC 40 index and the tick size is now 0.10 index point. The cash settlement at expiration is the difference between the exercise price and the expiration settlement index time EUR 1.[14] For each option series (calls and puts), at any given time, there are at least three strike prices available: one around the CAC 40 index value and two out-of-the-money strikes closest to the index value. In-the-money options are exercised automatically at expiration, unless specified otherwise by the buyer.[15]

For the sake of comparison, some summary statistics about trading in various index options from around the globe are reported in Table 1. The downsizing of the CAC 40 options contracts in 1999 has propelled them to the distinction of most actively traded (in terms of volume or number of contracts) index options in the world. In 2000, more than 84 million CAC 40 options contracts were traded on the MONEP. During the same year, S&P 500 options in the United States had a volume of 23.5 million contracts and the volume for the DAX options in Germany was 31.9 million. In terms of contract value, however, the CAC 40 options market is much smaller and rank fifth in the world behind S&P 500, DAX, NASDAQ 100 and FTSE 100.

The data for the CAC 40 index options for the January 1997 to December 1999 period were extracted from the *Euronext Paris* database. The database includes a time-stamped record of every trade that occurred on the MONEP, the dividends on the underlying stocks and the transaction volume for all call and put options. It also contains the CAC 40 index value caught

[13] Options on many of the CAC 40 component stocks are also traded on the MONEP. Equity options for more than 80 stocks are available for trading on the MONEP.
[14] 1 EUR = 6.55957 FRF.

every 30 seconds. We use the PIBOR until December 1998 and the EURIBOR afterwards as a proxy for the risk-free rate of interest. The interest rate data is from *Datastream*.[16] These interest rates are also used to calculate the present value of the dividends paid on the index prior to the expiration date of the option.

The availability of high frequency prices ensures a high level of synchronisation between the option prices and the index. This allows us to overcome a key problem related to tests of no-arbitrage opportunity. Further, in our sample, we require all prices in a given arbitrage condition to be within one minute of each other.[17] As usual, we use exclusion criteria to remove unreliable or likely uninformative (for our purpose) option records from the database. Options transactions with a reported price less than 1 index point, options with maturity less than two days or higher than 180 days are excluded from the sample.

While it is important to take transaction costs (bid-ask spread, commissions, trading fees, settlement fees, *etc.*) into account, an accurate estimation of the actual costs for the various strategies is quite challenging. Not only the transaction costs tend to vary over time, they may also depend on the particular strategy and the size of the transaction.[18] As bid and ask prices are not readily available for the French derivatives markets, we have to consider proxies.[19] A common approach is to assume that the bid-ask spread is constant. Then, it could be estimated based on a sample of bid-ask quotations (Phillips and Smith (1980)) or derived from the moments of the transaction prices (Roll (1984), Stoll (1989), Smith and Whaley (1994)).

In addition to the bid-ask spread, the overall transaction costs also include brokerage commissions and exchange fees. As of April 2000, for index options transactions on the MONEP, trading fee is equal to 0.02 Euro *per* contract and the clearing fee varies with the price of the option from 0.025 % of the contract value if it is less than 150,000 Euros to 0.15 % of the contract value if it is more than 1,500,000 Euros. In addition, there are taxes equal to 19.6 % of the fees.

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[15] More information is available at the web site *www.monep.fr*.
[16] We ignore the difference between the lending and borrowing rates.
[17] In order to increase our sample, we constructed other samples where prices are required to be within five minutes of each other. They lead approximately to the same results.
[18] Especially in the French market, fees varied with the shift to the Euro and the re-definition of the contract features.
[19] Bid-ask spread generally overestimates transaction costs since trades also occur inside the spread rather than at the quotes as the traders are sometimes able to bargain for better prices. In this case, the bid-ask quotes would not represent the effective prices. Thus, tests based on bid-ask spreads would be biased in favour of market efficiency.

In this study, we entertain four different scenarios for the overall transaction costs and short sale constraints.[20] In *Scenario 1*, we assume a zero bid-ask spread and test the arbitrage relations with the transaction prices. We assume here all other transaction costs to be zero and no short selling constraint is imposed either. Frequency and size of arbitrage opportunity is overestimated in this scenario. In *Scenario 2*, the option bid-ask spread is assumed to be equal to 1 % of the reported transaction price and the index bid-ask spread is assumed to be equal to 0.1 % of the reported index level. However, as before we assume away other transaction costs and no short-selling constraint is imposed either.

In *Scenario 3*, the bid-ask spreads are the same as in *Scenario 2*. However, we add exchange (MONEP) fee of 0.025 index points plus 0.2% of contract value for options and a brokerage commission of 5.0 index points (as in Cavallo and Mammola (2000)) for replicating the CAC 40 index. Further, as in prior studies (e.g., Kamara and Miller (1995), Ackert and Tian (1999, 2000)) we allow 99% of the sale proceeds to be available to the index short seller. The purpose here is to estimate the frequency of arbitrage opportunity for institutional arbitrageurs on the MONEP. In *Scenario 4*, the option bid-ask spread is assumed to be equal to 2.5 % of the reported transaction price and the index bid-ask spread is assumed to be equal to 0.25 % of the reported index level. The exchange (MONEP) fee here is 1.0 index point plus 1% of contract value for options. As *in Scenario 3*, the brokerage commission is 5.0 index points for replicating the CAC 40 index and 99% of the sale proceeds are available to the index short seller. Scenario 4 is the case of a retail investor who faces large bid-ask spreads, higher transaction costs as well as short-selling constraints.

4. Empirical Results

In this section, we discuss the empirical results regarding the efficiency of the CAC 40 index options market that are reported in Tables 2 through 8. All the results are ex-post except those for the Put-Call Parity where we also report findings of *ex-ante* experiments. In Appendix B, we describe the design of our *ex-post* (and *ex-ante* tests for the PCP) tests for the arbitrage conditions under study. Test results for the lower boundary conditions (*1a* and *1b*) are reported in

[20] These measures are based on private discussion with traders. In reality, the bid-ask spreads on the MONEP very likely varied over time and it was not possible on our part to estimate the time varying spreads accurately. However, we will see that this is not a serious limitation of our analysis since small spreads are enough to nullify arbitrage violations.

section 4.1, followed by the Put-Call Parity (*2a* and *2b*) results in section 4.2. These results in sections 4.1 and 4.2 thus concern efficiency in terms of absence of arbitrage across the stock and the options markets. Results about the internal efficiency of the CAC 40 index options market are discussed in the sections 4.3 through 4.5. The call and put spread (*3a* and *3b*) results are in section 4.3, the box spread (*4a* and *4b*) results are in section 4.4, and the convexity or butterfly spread (*5a* and *5b*) results follow in section 4.5.

In each section, as we report the French market evidence, we also compare them to the US market evidence reported in prior studies. The main statistics in our discussions is the frequency (or percentage or incidence) of violations of the arbitrage conditions defined as:

Frequency (Percentage or Incidence) of Violation =
Number of Violations Identified / Number of Observations Examined

Except for the lower boundary condition, we then report the size of violation as measured by the mean deviation in index points (referred to as *Mean* in the tables). The tables also report the standard deviation (in index points) of the deviations (referred to as *Std* in the tables).

4.1 Lower Boundary Condition

The first set of results reported in Table 2 corresponds to the test of the lower boundary conditions *(1a)* and *(1b)* using the transaction prices. Prices that violate these arbitrage conditions will not be considered in the remainder as they can be considered as outliers. To be quite conservative, we assume here that there are no transaction costs or constraints.

Of the 158,253 observations that remained after screening, the lower boundary condition appears to have been violated in only 807 (0.51%) option transactions. Of these, 682 (0.88% out of 77,927) are call option and 125 (0.16% out of 80,326) are put option transactions. These incidences compare quite favorably with those in the US and elsewhere. For example, Ackert and Tian (1999) report frequency of violations for the S&P 500 index options at more than 5% for call options and at more than 2% for put options during the February 1992 to January 1994 period. In the much smaller Finnish Options Index market during May 2, 1988 to December 21, 1990, Puttonen (1993) find about 7% violation for at-the-money call options with in-the-money options exhibiting a significantly greater incidence.[21]

The shift to the Euro and the associated changes in the CAC 40 options contract specification appears to have made a clear improvement in reducing the incidence of lower boundary violation from 1.82% to 0.41% for call options and from 0.29% to 0.10% for put options. The Z-statistics for the change in the percentage of violations, 16.03 (call), 5.10 (put) and 16.99 (combined), are all significant even at 1% significance level. These improvements are quite impressive compared to the effect of introducing tracking security SPDR for the S&P 500 and the trend in other markets. As reported by Ackert and Tian (1999), the introduction of SPDRs barley changed the frequency of call option lower boundary violations and in fact led to a deterioration for put options from 2.04% violation before to 2.64% after the introduction of SPDRs. Similarly and contrary to conventional wisdom, Puttonen (1993, Finnish Options Index), Halpern and Turnbull (1985, Canadian Equity Options), and Bhattacharya (1983, CBOE Equity Options) find the incidence of European call lower boundary violation to increase over time as the options markets attracted more volume.

Therefore, at least on the basis of the most fundamental arbitrage relationship for stock index and option prices, the French options market appears quite efficient, specially considering its smaller size (in terms of traded value of the underlying index) and age. Also, as the options market activity increased over time, the lower boundary violation became less frequent suggesting that traders perhaps became more familiar with the CAC 40 index options.

4.2 Put-call parity (PCP)

Empirical tests of the put-call parity for the US markets have been widely reported in the literature albeit with mixed findings.[22] While the PCP holds on average, there are frequent

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[21] Based on CBOE equity options transactions data for 196 trading days ending in June 2, 1977, Bhattacharya (1983) find the frequency of ex-post violation at 8%. This compares with Galais (1978) frequency of 2.95% for equity options during the first six months of CBOE operation in 1973. Using transactions data for the Canadian equity options market, Halpern and Turnbull (1985) report an ex-post violation incidence of around 10% during 1978 and 1979. They also find some inefficiency in ex ante tests after considering bid-ask spread and transaction costs.

[22] Klemkosky and Resnick (1979) and Nisbet (1992) find general compliance. Some inefficiency is reported by Stoll (1969), Gould and Galai (1974), and Evnine and Rudd (1985, S&P 100). Further, Finucane (1991, S&P 100) reports that deviations from the PCP are related to future spot returns. A number of studies have also examined the joint

violations of the PCP in ex-post tests that indicate some inefficiency. However, in *ex-ante* tests, the arbitrage profits are wiped away by the transaction costs.

Ex-post tests assume ability to simultaneously execute all legs of the arbitrage at the prices that to start with indicate a potential arbitrage opportunity.[23] In practice, this seems unrealistic, especially so for multi-market arbitrage and for smaller traders. Hence, in addition to *ex-post* test, we undertake *ex-ante* test to see whether traders can profit from orders executed with a time lag after the identification of violation of the PCP no arbitrage conditions. The details of these tests are given in Appendix B.

To investigate how the percentage of violations evolved with the shift to the Euro, we use the following Z-statistics for the difference between two proportions:

$$Z=(p_1-p_2)/\sqrt{[\,p_1(1-p_1)/N_1 + p_2(1-p_2)/N_2\,]}$$

where p_1 and p_2 are the percentage of violations (sample proportions) and N_1 and N_2 are the number of observations (sample sizes corresponding to the proportions) before (1997-1998) and after (1999) the shift to the Euro. This test is especially informative when the samples are large and the frequencies far from zero. The asymptotic distribution of the Z statistic is standard normal under the null hypothesis of no change in the frequency of violations due to the shift to the Euro and the associated changes in the options contracts.

In addition to the above, we also examine if arbitrage violations occur when the volume of transaction is abnormal. To do so, we use the following T-statistics for the difference between two means :

$$T=(x_1-x_2)/\sqrt{(s_1^2/N_1 + s_2^2/N_2)}$$

where x_1 and s_1 are the mean and the standard deviation of the volume over all cases, and x_2 and s_2 are the mean volume and the standard deviation of the volume when a violation occurs. The

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market efficiency of index options and futures contracts (Lee and Nayar (1993), Fung, Cheng and Chan (1997), Bae, Chan and Cheung (1998)).

[23] To emphasize the importance of synchronous prices, two sets of results have been computed. The first set of results was obtained with synchronous option and index prices. The second set of results was derived from options traded within five minutes of each other. Since there are no major differences between the two samples we provide only results obtained with the first set.

asymptotic distribution of the *T* statistic is standard normal under the null hypothesis of no relation between arbitrage violations and the volume of transaction.[24]

Panels A and B of Table 3 contain the ex-post test results for the PCP conditions *(2a)* and *(2b)* that prevent the *short* (short index and put, long call and risk-free asset) and the *long* (long stock and put, short call and risk-free asset) arbitrage strategies respectively. As shown in *Panel A(B)*, when there are no transaction costs (*Scenario 1*), the frequency of *short (long)* PCP violation is 58% (42%) over the whole sample (1997-1999). As shown by the *Mean* statistics, the size of the PCP violations is also substantial. The average deviation from the *short* (*long*) PCP condition is 17.13 (5.89) index points. With modest transaction costs (*Scenario 2*), the *short (long)* PCP violation frequency drops to 32% (17%). The violation frequency drops further to 8% (4%) in *Scenario 3* that better represents institutional traders' situation. From a retail trader's point of view in *Scenario 4*, the chances of a *short (long)* arbitrage opportunity are very small at 1.26% (0.04%). While the size of deviation from the PCP conditions exhibit some tendency to decline as the transaction costs increase, non-negligible profits still appear to exist for the few remaining arbitrage opportunities. For example, an institutional arbitrageur (*Scenario 3*) could still expect to net 15.19 (5.02) index points by arbitraging the *short* (*long*) PCP.

For the S&P 100 Index (American) options, Evnine and Rudd (1985) report 52% (*short* arbitrage) and 22% (*long* arbitrage) incidences of violation while according to Chance (1987) the violation frequencies are at 43% and 38% respectively. For the S&P 500 index (European) options, Kamara and Miller (1995) report ex-post violation frequencies at 23% (*short* arbitrage) and 10% (*long* arbitrage) with no short-selling constraint. When only 99% of the short sale proceeds are available, the violation frequencies drop to 3% and 5% respectively. In a more recent study of the S&P 500 index options, Ackert and Tian (1999) find the *short* and the *long* arbitrage conditions violated in 52% (38%) and 37%(50%) of the cases before (after) the introduction of the tracking security SPDR. Transaction costs and 99% short selling constraint effectively eliminate the PCP violations.[25] For the smaller and newer Italian index options market, Cavallo and Mammola (2000) report a 49% violation frequency for the *short* as well as the *long*

[24] As volumes increase with the shift to the Euro, we do not report global statistic about the significance of the volume spread with and without violations.

[25] Kamara and Miller (1995) as well as Ackert and Tian (1999) create daily bid and ask prices from their respective closing prices by adding or subtracting either 1/32 or a 1/16 of a point.

arbitrage.[26] Considering the bid-ask spread and other transaction costs, they find the violation frequency to drop to 2%.

Thus the ex-post PCP efficiency in the CAC 40 index options market seems similar to that in the S&P index options market in terms of frequency of violations. One further interesting aspect is that for both S&P and CAC 40, *short* PCP violations are more common than *long* PCP violations.[27] In the Italian market, there is no such difference. This evidence is somewhat puzzling given that establishing a short position in the underlying index or trading in the CAC 40 futures should be no more difficult than doing so for the MIB 30 index in Italy. There is, however, one area where the options markets of Italy and France have similar PCP experiences, namely the size of the PCP deviations. Unlike the US market, the size of the PCP deviations does not show marked improvement when allowing for higher transaction costs.

Ex-post PCP violations only indicate the possibility of arbitrage across the stock market and the index options. *Ex-ante* tests should show to what extent capturing profits from such arbitrage possibilities is possible. Two key statistics in this context are *Percentages (a)* and *(b)* of Table 4:

Percentage (a)=
100% (Number of *Ex-Ante* PCP Violations / Total Number of PCP Observations)

Percentage (b)=
100% (Number of *Ex-Ante* PCP Violations / Number of PCP Observations Available *Ex-Ante*)

Considering *Percentage (a)*, the incidence of PCP violations drop significantly to under 6% on an *ex-ante* basis even without considering transaction costs and short selling constraint and virtually disappears when these frictions are factored in. Ackert and Tian (1999) report similar *ex-ante* results for the S&P 500 index options although the incidence of PCP violation remains at

[26] For the Swiss equity options (American style) market, Lefoll (1994) undertakes *ex-post* and *ex-ante* tests of put-call parity for thirteen stocks from October 1989 to June 1990. Considering only the bid-ask spread component of transaction costs, he reports 1.1% (0.8%) and 0.5% (0.3%) *ex-post* (*ex-ante*) violation of the *short* and the *long* PCP arbitrage conditions respectively. Berg, Brevik and Saettem (1996) study Oslo Stock Exchange equity options (American style) on four stocks from May 1990 to July 1991. Taking transaction costs into account but using daily closing prices, they report a 54.5% frequency of violation of the ex-post put-call parity on 1,209 observations. Of the 659 violations, there are 503 (156) violations of the short (long) arbitrage strategies for an average profit of NOK 0.95 (0.97).

above 10% before considering the 99% short sale proceeds limitation. This is perhaps due to their use of daily data.

Percentage (b), however, reveals a potential concern for efficiency of the French markets. The frequency of violation seems quite high considering the number of put-call parity observations that are available *ex-ante*. For example, the 155 (Table 4) cases of ex-ante PCP violations of arbitrage condition *(2a)* represent only 5.58% (*Percentage (a)*, Table 4) of the total pool of 2,780 (Table 3) PCP observations for 1997-1999. But these 155 cases constitute 87.08% (*Percentage (b)*, Table 4) of the 178 (Table 4) instances of *short* PCP arbitrage that were available *ex-ante* given our fifteen minutes execution window and ignoring transaction costs. Moreover, this percentage remains high even after considering transaction costs. Therefore, one interpretation of our evidence is that the MONEP pricing of CAC 40 options is quite efficient most of the times in preventing arbitrage across the cash and options markets. Occasionally, however, when a PCP arbitrage opportunity is identified, it is quite likely that a profitable arbitrage can be implemented.

In terms of the size of deviation from the PCP conditions, the *ex-ante* evidence indicates profitability for an institutional but not a retail arbitrageur. After taking into account bid-ask spread, fees, commissions and short selling constraint, an institutional arbitrageur (Scenario 3) could expect to make 19.13 (6.32) index points by detecting a *short* (*long*) PCP violation and then executing the arbitrage over the next fifteen minutes. Thus, while the likelihood of a profitable PCP arbitrage diminishes on an *ex-ante* basis, any remaining opportunity appears quite lucrative from an institutional arbitrageur's point of view.

Based on the 1997-1998 and 1999 results in Tables 3 and 4 and the associated Z-statistic, the shift to the Euro and the contract changes that took place starting in 1999 do not show any clear impact on PCP efficiency. In *Panel A* of Tables 3 and 4, there is some evidence of improvement in efficiency with respect to the *short* arbitrage strategy after the shift to the Euro.

The mean volume spread figures in Tables 3 and 4 show the difference between the average volume of all transactions net of the average volume of transactions in violation of the PCP. A negative mean volume spread shows coincidence of PCP violation with a brisk market situation. As the *ex-ante* results in this context are perhaps not as meaningful, we only discuss the *ex-post* results in Table 3. A comparison of the mean volume spreads in *Panels A* (*short* strategy)

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[27] For instance, Klemkosky and Resnick (1980) and Nisbet (1992) report a greater incidence of short PCP violation

and *B* (*long* strategy) of Table 3 reveals that *short (long)* arbitrage PCP violation is more prevalent when the options market is relatively busy (calm) especially following the shift to the Euro. In general, the T-statistics show that this options volume pattern is significant, more so for the *long* strategy PCP violation.

In this paper we do not investigate the determinants of arbitrage condition violations. However, it is worthwhile to briefly explore if the PCP violations reported here are systematically related to factors previously cited in the literature. For the S&P 500 Index options both Kamara and Miller (1995) and Ackert and Tian (1999) that the *ex-post* PCP violations are greater when options are away from the money, the market is more volatile, index volume is low, and option's open interest is low. For the post-1987 crash period when the longer maturity options volume declined, Kamara and Miller find PCP violations to increase with time to expiration. Ackert and Tian, on the other hand, find opposite effects of time to expiration for the violations of the short (synthetic borrowing) and long (synthetic lending) strategy arbitrage conditions. For the short (long) strategy condition 2a (2b), they find the violations to decrease (increase) with time to expiration.

As argued by Kamara and Miller, most of the factors that appear to affect the PCP violations can be considered as proxies for the risk of not being able to execute all legs of the arbitrage in time and at favorable prices following the identification of an arbitrage opportunity. Options that are away from the money and have long maturity usually do not attract as much trading activity. There is also some evidence (Jameson and Wilhelm (1992)) that the bid-ask spread increases as the option moves further from at-the-money. Hence the execution risk is usually greater for these options. The execution risk is magnified when the equilibrium price volatility for the underlying asset is higher and any delay in execution can wipe out or even reverse the potential arbitrage profits. Low volume in the underlying asset and the options market also enhances execution risk by increasing the expected time for the orders to be filled, especially for large scale arbitrage transactions.

Whatever is the reason, if the execution risk is higher, arbitrageurs would engage in arbitrage transactions only if the profits are sufficiently higher as well. This means for the short (long) strategy, the put option bid (ask) price needs to be higher (lower) and the call option ask (bid) needs to be lower (higher). Stated differently, the synthetic borrowing (lending) rate needs

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than long PCP violation for CBOE and London equity options.

to be lower (higher) relative to the risk-free rate. Interestingly, the existence of and increase in execution risk premium require that the bid-ask spread of all call and put options be reduced, more so where the execution risk is higher. To the extent the actual bid-ask spreads behave in this fashion, PCP violations would *appear* to be more severe, although the apparent arbitrage profit likely reflects the execution risk premium.

To see if the PCP violations are related to proxies for the execution risk, we present in Table 5 the number and frequency of PCP violations and the mean and standard deviation of absolute PCP deviations (arbitrage profits) under *Scenario 1* (no frictions) for nine groups of options. For this grouping, options are classified as at-the-money (ATM) if the index value is within 5% of the strike. Otherwise, they are considered out-of-the-money (OTM) or in-the-money (ITM) depending on whether the index value is lower or higher than the strike.[28] The time to expiration for the three maturity classifications are 2 to 90 days for short-term, 91 to 120 days for medium-term and 121 to 180 days for long-term options. Since the *ex-post* and *ex-ante* results are similar in spirit, we only discuss below the *ex-post* results in Table 5.

Naturally the number of *ex-post* violations is the highest *(829 for the short and 831 for the long arbitrage condition)* for short-term at-the-money options as they are typically the most actively traded options. For the *short* arbitrage condition (2a), the frequency (percentage or incidence) and the size and dispersion of PCP deviations (arbitrage profit) all seem to increase as the time to expiration increases. An opposite pattern of frequency and a U-shaped pattern of the size of PCP violations are observed for the *long* arbitrage condition (2b). In terms of the execution risk explanation, the *short* arbitrage evidence indicates that it is perhaps more difficult for the arbitrageurs to execute the strategy of short selling the index, selling the put option and buying the call option as maturity gets longer. This may result from a shortage of put buyers (requiring put bid price to be higher) and call sellers (requiring call ask price to be lower), i.e., a shortage of investors who prefer to trade in longer-term options in seeking portfolio insurance or betting against a rally of the CAC 40. The flip side, based on the *long* arbitrage violations, is that perhaps there are more speculators who prefer to use the medium-term options (sell put and/or buy call) to bet on a CAC 40 rally. To summarize, the time to expiration effect in the CAC 40 options market seems consistent with a preference of short-term (medium-term) options by the portfolio insurers and bearish speculators (bullish speculators).

Considering the frequency of PCP violations by moneyness of the options, unlike the US evidence, we do not find any consistent pattern of the frequency increasing for options moving away from at-the-money. In terms of the size of the PCP deviation (arbitrage profit), there is rather strong evidence that the deviation is the highest for at-the-money options and tends to go down for in-the-money and out-of the-money options. For example, for the short-term options where the frequency of the *short* arbitrage violation is the lowest, the mean PCP deviations in *Panel A* of Table 5 are 6.02 (OTM: out-of-the-money calls, in-the-money puts), 8.45 (ATM: at-the-money calls, at-the-money puts), and 6.54 (ITM: in-of-the-money calls, out-of-the-money puts) index points. In *Panel B* of Table 5, the mean deviations from the *long* arbitrage condition using short-term options are 4.22, 6.16 and 5.30 index points respectively for the OTM, ATM and ITM groups.

Based on the group results in Table 5, it seems that the systematic patterns of PCP violations in the CAC 40 options market are a bit different from those observed in the S&P 500 options market. Therefore, the execution risk explanation could apply to both markets if institutional and cultural factors lead to differential preferences for options maturity and strike by investors in the two markets. Or perhaps there are other explanations behind the PCP violations. One caveat is that our exploration of the systematic pattern in CAC 40 PCP violations is quite limited in scope and differs from the more rigorous regression methodologies used by Kamara and Miller (1995) and Ackert and Tian (1999) for the S&P 500 options market. It remains to be seen if the differences in methodology could explain the differences in findings.

4.3 Call & Put Spreads

Using daily closing data for the S&P 500 index options during the 1986-1996 period, Ackert and Tian (2000) find 2.05% (0.40%) frequency of ex-post violation of the call (put) spread condition. As an indication of *ex-ante* violation, they find 8.04% (6.72%) of the call (put) spread violations to persist into the next trading day. Moreover, they find no discernible improvement in efficiency of the S&P 500 options market in terms of call and put spreads over the eleven-year period.

Panel A (B) of Table 6 presents our ex-post call (put) spread test results for the CAC 40 index options. When there are no transaction costs (*Scenario 1*), the frequency of call (put) spread

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[28] Thus, our definition of moneyness indicates the moneyness of call options. Our in-the-money options group, for

violation is 0.34% (0.01%) over the whole sample (1997-1999). Even with modest transaction costs (*Scenario 2*), the call (put) spread violation frequency changes to 0.02% (0.01%). The violation frequency drops further to 0.01% (0.01%) for call (put) options in *Scenario 3* and virtually disappears in *Scenario 4*. Thus, considering transaction costs, our ex-post spread results confirm a high level of options market efficiency (in terms of frequency of violations) in relative pricing of options of a given type (call or put) in the French index options market [29]

In contrast to the frequency of violations, the size of the deviations does not show any improvement (except *Scenario 4*) and in fact deteriorates in many instances as the bid-ask spread, exchange fees, commissions and short-selling constraint are considered. The average deviation from the call (put) spread condition is 2.11 (9.98) index points under *Scenario 1* where none of these market frictions are taken into account. According to *Scenario 3*, during the 1997-1999 period, an institutional arbitrageur could expect to net 11.84 (16.17) index points from the call (put) spread after taking into account all the market frictions. However, this evidence of inefficiency is mitigated by the fact that profitable spread arbitrage opportunities are rather rare. There are only three (two) instances of call (put) spread violation from an institutional trader's perspective (*Scenario 3*) during a three-year period. In other words, as the arbitrage opportunities become rare, any remaining ones could potentially generate sizeable arbitrage profit.

Except for Scenario 1 (no bid-ask spread, no commissions or constraints), the shift to the Euro and the contract changes that took place starting in 1999 had no impact on the efficiency of the call and put options in terms of spread.

4.4 Box Spread

Empirical evidence on the box spread and spreads in general is not as extensive as that on the put-call parity. Earlier Ronn and Ronn (1989) studied *ex-ante* profitability of box spreads for a number of stocks using CBOE options data on eight different days during the 1976-1984 period. They find that non-negligible arbitrage profits are available only if the transaction costs are low and the arbitrage transactions can be implemented within a few minutes of detecting the possibility. Ackert and Tian (1999, 2000) report box spread evidence for the S&P 500 index

example, comprises of in-the-money call options and out-of-the-money put options.

[29] We could not conduct ex-ante tests for the spreads as the number of ex-post violations were too small. For the same reason, we did not undertake the mean volume spread test for the call and put spreads.

options during the 1986-1996 period using daily closing data. Taking into account the bid-ask spread and the various transaction costs, they find *ex-post* percentage of violations around 20% and in 4% (1986) to 12% (1990) of the cases a box spread violation persisted into the next day, a situation Ackert and Tian define as an *ex-ante* violation. There was no discernible improvement in the box spread efficiency of the S&P 500 options market over the eleven-year period.

Our ex-post box spread results for the CAC 40 index options are presented in Table 7. As shown in *Panel A*, when there are no transaction costs (*Scenario 1*), the frequency of *long* box spread violation is 43% over the whole sample (1997-1999). However, even with modest transaction costs (*Scenario 2*), the *long* box spread violation frequency drops to 13%. The violation frequency drops further to 10% in *Scenario 3* that better represents institutional traders' situation. From a retail trader's point of view in *Scenario 4*, there is no arbitrage opportunity at all. The *Panel B* results for the *short* box spread are fairly similar. Thus, considering transaction costs as in Ackert and Tian (1999,2000), our box spread results indicate a greater level of internal options market efficiency (in terms of frequency of violation) in the French index options market than in the US.

In contrast to the frequency of violations, the size of the deviations does not show any improvement (except *Scenario 4*) and in fact deteriorates in some instances as the bid-ask spread, exchange fees, commissions and short-selling constraint are considered. The average deviation from the *long (short)* box spread condition is 2.65 (2.98) index points under *Scenario 1* where none of these market frictions are taken into account. According to *Scenario 3*, during the 1997-1999 period, an institutional arbitrageur could expect to net 2.07 (3.64) index points from the *long (short)* box spread after taking into account all the market frictions. This evidence of inefficiency is somewhat unsettling given that profitable box spread arbitrage opportunities are not as uncommon as it is in the case of call and put spreads. There were 21 (16) instances of *long (short)* box spread violation from an institutional trader's perspective (*Scenario 3*) during a three-year period.

Ironically, the shift to the Euro and the contract changes that took place starting in 1999 had a negative impact on box spread efficiency. The frequency of box spread violations increased following the shift and the increase is statistically significant as shown by the *Z* statistics. In fact, from an institutional trader's point of view in *Scenario 3*, while there is no opportunity of box spread arbitrage before the shift, there is 9% (*short*) to 12% (*long*) chance of a profitable box spread arbitrage after the shift. This result is somewhat puzzling given that, for short-term CAC 40 options, more strike prices have become available and the strike prices have become closer (separated by 50 index points instead of 150 index points) since 1999.

It would have been informative to see if the arbitrage opportunities persist in *ex-ante* tests. Unfortunately, the number of *ex-post* violations is too small in our study to make the *ex-ante* tests informative. Besides, when the *ex-ante* tests are conducted, the frequency of simultaneous observations is too low to have another set of simultaneous observations in the 15-minutes interval used in our study. The main reason for this difficulty is that the box spreads require simultaneous trading of four options as opposed to two for the call or put spreads and the PCP.

It is interesting to note that the mean volume spread between all box spread observations and the ones where there is a violation of the arbitrage condition is mostly negative, although not statistically significant. Thus there is some indication that the CAC 40 box spread arbitrage opportunities are more likely to occur when the markets are busier. This evidence appears consistent with the effect of the shift to the Euro that led to more volume in the options market but a higher frequency of violations too.

4.5 Call & Put Convexities (Butterfly Spreads)

Empirical evidence on option convexities is rather shallow. Galai (1979) test convexity condition on CBOE call options during April 26, 1973 to October 30, 1973. Using closing prices he finds 2.4% incidence of violation of the call convexity condition.[30] However, the frequency of violations greatly diminishes when intra-day transactions are used instead.[31] Using daily closing data for the S&P 500 index options during the 1986-1996 period, Ackert and Tian (2000) find 3.08% (0.91%) frequency of ex-post violation of the call (put) convexity condition.[32] As an indication of *ex-ante* violation, Ackert and Tian find 6.1% (4.13%) of the call (put) convexity violations to persist into the next trading day. Once again Ackert and Tian find no discernible

[30] The violations took place for six of the thirteen stocks and all the options involved were in-the-money options.
[31] Bhattacharya (1983) reports the strongest support for call convexity in his transactions data sample of CBOE options on 58 stocks during August 24, 1976 to June 12, 1977.
[32] Ackert and Tian take into account the bid-ask spread and the various transaction costs in their test of ex post violations.

improvement in efficiency of the S&P 500 options market in terms of convexity over the eleven-year period.

Panel A (B) of Table 8 presents our ex-post call (put) convexity test results for the CAC 40 index options. When there are no transaction costs (*Scenario 1*), the frequency of call (put) convexity violation is 1.34% (2.47%) over the whole sample (1997-1999). However, even with modest transaction costs (*Scenario 2*), the call (put) convexity violation frequency drops to 0.46% (1.16%). The violation frequency drops further to 0.23% (0.52%) for call (put) options in *Scenario 3* and literally disappears in *Scenario 4*. there is no arbitrage opportunity at all. The *Panel B* results for the *short* box spread are fairly similar. Thus, considering transaction costs as in Ackert and Tian (2000), our convexity results reconfirm a greater level of internal options market efficiency (in terms of the frequency of violations) in the French index options market than in the US.

In contrast to the frequency of violations, the size of the deviations does not show any improvement (except *Scenario 4*) and in fact deteriorates in some instances as the bid-ask spread, exchange fees, commissions and short-selling constraint are considered. The average deviation from the call (put) convexity condition is 1.54 (2.16) index points under *Scenario 1* where none of these market frictions are taken into account. According to *Scenario 3*, during the 1997-1999 period, an institutional arbitrageur could expect to net 1.40 (4.05) index points arbitraging the call (put) convexity after taking into account all the market frictions. This evidence of inefficiency is unsettling given that profitable convexity arbitrage opportunities are much more common than in the case of call and put or box spreads. There were 52 (161) instances of call (put) convexity violation from an institutional trader's perspective (*Scenario 3*) during a three-year period.

The shift to the Euro and the contract changes that took place starting in 1999 had differential impacts on the efficiency of the call and put options in terms of convexity. Considering transaction costs, the frequency of call convexity violations increased following the shift while the frequency of put convexity violations decreased. The changes are statistically significant as shown by the Z statistics although the magnitude of change is rather small. Like the box spreads, we could not conduct *ex-ante* tests of the convexity conditions due to the paucity of data.

Since the number of convexity violations is generally low, we could meaningfully conduct the mean volume spread test in a limited number of situations only. Most of these cases, however, show a statistically significant difference in volume between an average situation and an incidence of convexity violation. In contrast to the box spread evidence, opportunities to arbitrage the CAC 40 convexities are more likely to occur when trading activity in the market is on the lighter side.

5. Summary and Conclusion

This paper examined the efficiency of the French options market MONEP using intra-day data on CAC 40 index options during the January 1997 through December 1999 period. The empirical results that we presented are not dependent on the validity of any theoretical option pricing model. This is because we only investigate violations of some well-known general arbitrage pricing relations between the underlying asset (CAC 40) and the options, namely, lower boundary condition, put-call parity (PCP), call and put spreads, box spreads and call and put convexities or butterfly spreads. The spreads allow us to examine the internal efficiency of the French options market regardless of its efficiency relative to the cash market for the stocks underlying the CAC 40 index. Further, we incorporate various market frictions (bid-ask spread, exchange fees, brokerage commissions, and short sale constraint) into our tests. Studies of newer and smaller options markets especially using spreads and high frequency data and including various market frictions are rather sparse.

The most fundamental of all the arbitrage relations is the lower boundary or intrinsic value condition for options. We find below one percent incidence of lower boundary violation in the CAC 40 index options market. This evidence compares quite favorably with the above one percent incidence in the S&P 500 index options market (Ackert and Tian (1999)).

With respect to the put-call parity, the *ex-post* PCP efficiency in the CAC 40 index options market seems similar to that in the S&P index options market in terms of frequency of violations. With the market frictions taken into account, *ex-post* profitable PCP arbitrage opportunity diminishes significantly and is virtually non-existent for retail traders. Our results show that on an *ex-ante* basis, the incidence of PCP violations drop significantly even without considering transaction costs and short selling constraint and virtually disappears when these frictions are factored in. Ackert and Tian (1999) report similar ex-ante results for the S&P 500 index options.

One interesting aspect is that similar to the case of the S&P index options, *short* PCP violations are more common than *long* PCP violations for the CAC 40 index options. In the Italian market, there is no such difference. There is, however, one area where the smaller markets of Italy and France have similar PCP experiences, namely the size of the PCP deviations. Unlike the US market, the size of the PCP deviations does not show marked improvement if at all when allowing for higher transaction costs. The institutional traders with low transaction costs could expect to undertake profitable arbitrage involving the index and the options in the instances when such opportunities arise.

We also find the systematic patterns in CAC 40 PCP violations to be different from those observed in the S&P 500 options market. Opposite to the S&P 500 market (Ackert and Tian (1999)), the *short* arbitrage PCP violations become more severe as the CAC 40 options maturity gets longer and the severity of *long* arbitrage PCP violations exhibits a U-shaped pattern with respect to maturity. Also, in contrast to the S&P 500 market (Kamara and Miller (1995) and Ackert and Tian (1999)), the frequency of PCP violations does not show any clear link to moneyness of the CAC 40 options while the size of the violations is lower for options that are away from at-the-money. To the extent moneyness and time to maturity are proxies for the risks of implementing arbitrage transactions and the premium for this risk causes PCP violations, institutional and cultural differences in the French and the US index options markets are perhaps in play. Since we do not examine the systematic patterns of PCP violations in as much details and methodological rigor as Kamara and Miller and Ackert and Tian, it remains to be seen if the methodological differences would explain the differences in findings.

Considering transaction costs, our *ex-post* results for the various spreads confirm a high level of internal options market efficiency (in terms of frequency of violations) in the French index options market. The number of violations was so low that we could not meaningfully conduct any *ex-ante* test for the spreads. The internal efficiency of the CAC 40 options market seems either comparable (call and put spreads) to the S&P 500 or better (box spreads and convexities).

Counteracting this surprisingly positive aspect of the French options market, the size of the deviations does not show any improvement (except for the highest cost retail traders) and in fact deteriorates in many instances as the bid-ask spread, exchange fees, commissions and short-selling constraint are considered. In the worst case of violation, an institutional arbitrageur could expect to net 11.84 (16.17) index points from the call (put) spread after taking into account all the market frictions. However, this evidence of inefficiency is mitigated by the fact that there were only three such (two) instances of call (put) spread violation during the three-year period. Although the instances of box spread and convexity violations are relatively more common, the arbitrage profits are much smaller.

Considering the incidence (frequency/percentage) of violation for the call and put spreads, the box spreads and the call and put convexities, it seems that the markets for the CAC 40 call and put options are somewhat segmented. Efficient relative pricing of options of different strikes within a type (call or put) occur with greater frequency than efficient relative pricing of options of different types. Moreover, efficient relative pricing of put options of different strikes seems to take place more frequently than the call options of different strikes. Offsetting this is the evidence that when arbitrage violations occur the put options arbitrage strategies seem to offer higher profit potential.

In this paper we also had an opportunity to study how major structural changes affect the efficiency of the options market. With the shift to the Euro, there were some major changes in the specification of the CAC 40 index options starting in 1999. We, therefore, examined the post-Euro period (1999) separately from the pre-Euro period (1997-1998). While the options market volume improved significantly following the structural change, we do not find any clear evidence of enhanced efficiency. In fact, efficiency was adversely affected in some instances. One possible factor behind this result is that the contract changes following the switch to Euro diminished the index options contract's cash value to about one-seventh of the pre-Euro value. However, the minimum tick size increased from about FRF 0.50 to FRF 0.656. Thus, in the post-Euro period, the tick size represents a larger ratio to the level of index option prices. Since the larger tick does not allow smaller adjustments in option prices in the post-Euro period, the option transaction prices would appear to be misaligned more often and the deviations are likely to be larger as well.

As the options volume increased manifold in the post-Euro period, we further examined if there is any association between brisk trading in the options market and the availability of arbitrage opportunities. We find some evidence although not conclusive that arbitrage opportunities are more common during periods of brisk index options trading. However, we do not attempt to establish any causality in this regard.

The empirical evidence in this paper raises several issues. First, structural and contract changes that increase options volume certainly enhance the income and thus the chances of survival and growth for the sponsoring exchange and the brokers/market makers. It is, however, not clear whether the investors are better off as we did not find any clear evidence of improved pricing efficiency following such changes in the French options market. Second, trading in the spot instruments and the options is more automated and integrated in France than in the US. We found that the French index options market is as efficient as (if not better than) the US index options market although the latter is much larger (in contract value) and more mature. Thus, our evidence seems to support the view that automation and integration promote market efficiency.[33] Third, although the frequency of arbitrage conditions violation is similar in the French and US index options markets, the systematic patterns of these violations appear different. This indicates that the cultural/institutional factors could be important in the context of derivatives market microstructure. Therefore, researchers in this area should consider control for cultural/institutional differences in inter-country studies and for structural changes in time series studies.

[33] In a recent paper, Venkataraman (2001) reports that the execution costs for similar stocks are higher on the Paris Bourse than on the NYSE and attributes this to the benefits of human intermediation on the NYSE. In the discussion of Venkataraman's paper, Madhavan (2001) suggests that Venkataraman's conclusion may be premature as there are many other differences (e.g., availability of alternative trading systems, insider trading rules, macro risk factors, overall level of market activity, et cetera) between the two markets that could contribute to differences in execution costs.

References

Ackert, Lucy F. and Yisong S. Tian, 1998, The Introduction of Toronto Index Participation Units and Arbitrage Opportunities in the Toronto 35 Index Option Market, *Journal of Derivatives*, 5(4), 44-53.

Ackert, Lucy F. and Yisong S. Tian, 1999, Efficiency in Index Options Markets and Trading in Stock Baskets, *Working Paper* 99-5, Federal Reserve Bank of Atlanta.

Ackert, Lucy F. and Yisong S. Tian, 2000, Evidence on the Efficiency of Index Options Markets, *Federal Reserve Bank of Atlanta Economic Review*, 40-52.

Bae, K.-H., K. Chan and Y.-L. Cheung, 1998, The Profitability of Index Futures Arbitrage: Evidence from Bid-Ask Quotes, *Journal of Futures Markets* 18 (7), 743-763.

Bates, David S., 1996, Testing Option Pricing Models, in Handbook of Statistics Series, vol. 14: *Statistical Methods in Finance* , G.S. Maddala and C.R. Rao (Eds.), Amsterdam: North-Holland, 567-611.

Berg, Egil, Trond Brevik and Frode Saettem, 1996, An Examination of the Oslo stock Exchange Options Market, *Applied Financial Economics* 6, 103-113.

Bhattacharya, M., 1983, Transaction Data Tests of the Efficiency of the Chicago Board Options Exchange, *Journal of Financial Economics*, 12(2), 161–186.

Billingsley, Randall S. and Don Chance, 1985, Options Market Efficiency and the Box Spread Strategy, *Financial Review*, 20(4), 287-301.

Black, F., 1975, Fact and Fantasy in the Use of Options, *Financial Analysts Journal*, 31(4), 36-41, 61-72.

Black, F. and M. Scholes, 1972, The Valuation of Option Contracts and a Test of Market Efficiency, *Journal of Finance*, 27(2), 399-417.

Black, F. and M. Scholes, 1973, The Pricing of Options and Corporate Liabilities, *Journal of Political Economy*, 81(May-June), 637-659.

Canina, Linda and Stephen Figlewski, 1993, The Informational Content of Implied Volatility, *Review of Financial Studies*, 6(3), 659-681.

Capelle-Blancard, Gunther, 2001, Efficiency and Microstructure of Derivatives Market: The Case of the MONEP, *Ph.D. thesis*, University Paris I Panthéon-Sorbonne.

Cavallo, Laura and Paolo Mammola, 2000, Empirical tests of Efficiency of the Italian Index Options Market, *Journal of Empirical Finance* 7, 173–193.

Chance, Don M., 1986, Empirical Tests of the Pricing of Index Call Options, *Advances in Futures and Options Research*, 1, 141-166.

Chance, Don M., 1987, Parity Tests of Index Options, *Advances in Futures and Options Research*, 2, 47-64.

Chaudhury, Mohammed M., 1985, On Testing the Black-Scholes Option Pricing Model, *Ph.D. thesis*, Burnaby, B.C, Canada: Simon Fraser University.

Chiras, Donald P. and Steven Manaster, 1978, The Information Content of Option Prices and a Test of Market Efficiency, *Journal of Financial Economics*, 6(2/3), 213-234.

Cotner, John S. and James F. Horrell, 1989, An Analysis of Index Option Pricing, *Journal of Futures Markets*, 9(5), 449-459.

Day, Theodore and Craig M. Lewis, 1992, The Behavior of the Volatility Implicit in the Prices of Stock Index Options, *Journal of Econometrics*, 52(1/2), 267-287.

DeRoon, Frans, Chris Veld and Jason Wei, 1995, A Study on the Efficiency of the Market for Dutch Long Term Call Options, *Center for Economic Research* Working Paper, Tilburg University.

Evnine, Jeremy and Andrew Rudd, 1985, Index Options: The Early Evidence, *Journal of Finance*, 40(3), 743-756.

Figlewski, Stephen and Gwendolyn Webb, 1993, Options, Short Sales and Market Completeness, *Journal of Finance* 48(2), 761–777.

Finnerty, Joseph, 1978, The Chicago Board Options Exchange and Market Efficiency, *Journal of Financial and Quantitative Analysis*, 13(1), 29-38.

Finucane, Thomas J., 1991, Put Call Parity and Expected Returns, *Journal of Financial and Quantitative Analysis*, 26(4), 445-457.

Fung, Joseph K.W., Louis T.W. Cheng and Kam C. Chan, 1997, The Intraday Pricing Efficiency of Hong Kong Hang Seng Index Options and Futures Markets, *Journal of Futures Markets* 17(7), 797-815.

Galai, Dan, 1977, Tests of Market Efficiency of the Chicago Board Options Exchange, *Journal of Business*, 50(2), 167-197.

Galai, Dan, 1978, Empirical Tests of Boundary Conditions for CBOE Options, *Journal of Financial Economics*, 6(2/3), 187-211.

Galai, Dan, 1979, A Convexity Test for Traded Options, *Quarterly Review of Business and Economics*, 19, 83-90.

Galai, Dan, 1983, A Survey of Empirical Tests of Option Pricing Models, in *Option Pricing: Theory and Applications*, Brenner, Menachem (ed.), MA: Lexington Books, Lexington, 45-80.

Gould, John P. and Dan Galai, 1974, Transaction Costs and the Relationship between Put and Call Prices, *Journal of Financial Economics*, 1(2), 105-129.

Halpern Paul J. and Stuart .M. Turnbull, 1985, Empirical Tests of Boundary Conditions for Toronto Stock Exchange Options, *Journal of Finance* , 40(2), 481-500.

Jameson, Mel and William Wilhelm , 1992, Market Making in the Options Markets and the Cost of Discrete Hedge Rebalancing, *Journal of Finance*, 47(2), 765-779.

Kamara, Avraham and Thomas W. Miller, Jr., 1995, Daily and Intradaily Tests of European Put-Call Parity, *Journal of Financial and Quantitative Analysis*, 30(4), 519-539.

Klemkosky, Robert C. and Bruce G. Resnick, 1979, Put-Call Parity and Market Efficiency, *Journal of Finance*, 34(5), 1141-1155.

Klemkosky, Robert C. and Bruce G. Resnick, 1980, An Ex-Ante Analysis of Put-Call Parity, *Journal of Financial Economics*, 8(4), 363-378.

Latane, Henry A. and Richard J. Rendleman, Jr., 1976, Standard Deviations of Stock Price Ratios Implied in Option Prices, *Journal of Finance*, 31(2), 369-381.

Lee, Jae Ha and Nandkumar Nayar, 1993, A Transaction Data Analysis of Arbitrages between Index Options and Index Futures, *Journal of Futures Markets*, 13(8), 889-902.

Lefoll Jean, 1994, Coûts de transaction et parité des options sur actions du SOFFEX, *Journal de la Société Statistique de Paris*, 135 (2), 19-38.

Madhavan, Ananth, 2001, Discussion, *Journal of Finance*, 56(4), 1485-1488.

Merton, Robert, 1973a, Theory of Rational Option Pricing, *Bell Journal of Economics and Management Science*, 4, 141-183.

Merton, Robert, 1973b, The Relationship between Put and Call Option Prices: Comment, *Journal of Finance*, 28(1), 183-184.

Nisbet, Mary, 1992, Put-Call Parity Theory and An Empirical Test of the Efficiency of the London Traded Options Market, *Journal of Banking and Finance*, 16(2), 381-403.

Poon, Ser-Huang and Peter F. Pope, 2000, Trading Volatility Spreads: A Test of Index Option Market Efficiency, *European Financial Management*, 6(2).

Phillips, Susan .M. and Clifford W. Smith, Jr., 1980, Trading Costs for Listed Options: The Implications for Market Efficiency. *Journal of Financial Economics*, 8(2), 179-201.

Puttonen, Vesa, 1993, Boundary Conditions for Index Options: Evidence form the Finnish Market, *Journal of Futures Markets* , 13(5), 545-562.

Roll, Richard, 1984, A Simple Implicit Measure of the Effective Bid-Ask Spread in an Efficient Market, *Journal of Finance*, 39(4), 1127-1139.

Ronn, Aimee G. and Ehud I. Ronn, 1989, The Box-Spread Arbitrage Conditions: Theory, Tests, and Investment Strategies, *Review of Financial Studies* 2 (Spring), 91-108.

Schmitt, Christian and Jürgen Kaehler, 1996, Delta-Neutral Volatility Trading with Intra-day Prices : An Application to Options on the DAX, *ZEW Discussion Paper* 96-25.

Sheikh, Aamir, 1991, Transaction Data Tests of S&P 100 Call Option Pricing, *Journal of Financial and Quantitative Analysis*, 26(4), 459-475.

Shimko, David C., 1993, Bounds of Probability, *Risk* 6, 33-37.

Smith, Tom and Robert Whaley, 1994, Estimating the Effective Bid-Ask Spread from Time and Sales Data, *Journal of Futures Markets*, 14(4), 437-455.

Stoll, Hans, 1969, The Relationship between Put and Call Option Prices, *Journal of Finance*, 24(5), 801-824.

Stoll, Hans, 1989, Inferring the Components of the Bid-Ask Spread: Theory and Empirical Tests, *Journal of Finance*, 44(1), 115-134.

Venkataraman, Kumar, 2001, Automated Versus Floor Trading: An Analysis of Execution Costs on the Paris and New York Exchanges, *Journal of Finance*, 56(4), 1445-1485.

Whaley, Robert, 1982, Valuation of American Call Options on Dividend-Paying Stocks: Empirical Tests, *Journal of Financial Economics*, 10(1), 29-58.

Table 1: Summary Statistics on Index Options

	Exchange	Volume in EUR Million			Traded Contracts			Open Interest in I	
		1998	1999	2000	1998	1999	2000	End 1998	End 19
	CBOE	2,493,527	2,950,819	3,635,318	25,708,136	23,313,805	23,548,454	181,510	275,6
	CBOE	183,944	318,667	954,945	1,565,244	1,273,270	2,538,044	3,191	31,6
A	CBOT	18,904	22,911	23,259	245,398	229,560	200,379	1,079	1,7
	EUREX	755,282	860,679	1,120,168	29,948,503	32,613,783	31,941,562	24,317	43,3
	MONEP	312,002	355,281	525,016	2,752,536	75,652,724	84,036,775	27,641	50,1
	LIFFE	331,160	472,775	655,562	3,968,199	4,897,934	6,285,819	29,921	56,5
	IDEM	263,288	399,031	327,534	1,577,621	2,236,241	2,842,081	7,081	20,1
	MEFF RV	94,864	87,569	85,464	1,681,205	861,255	779,974	161	8,2
	EUREX	254,431	230,480	170,011	3,394,098	3,669,386	3,474,369	19,392	11,8
	AEX	354,254	289,954	310,733	7,864,884	5,532,409	4,701,906	28,571	42,7
X 50	EUREX/MONEP	6,950	149,707	419,520	229,408	3,922,787	8,236,355	1,643	38,3

Chicago Board Options Exchange, CBOT: Chicago Board of Trade, MONEP: Marché des Options Négociables de Paris (Euronext Paris), L nancial Futures and Options Exchange, IDEM: Italian Derivatives Market, MEFF RV: Mercado de Opciones y Futuros Renta Variable, AE onext Amsterdam). *Source*: Eurex Monthly Statistics Derivatives Market.

Table 2: Violation of European Options Lower Boundary Condition

Table 2 reports the number and the percentage of violations of the following lower boundary conditions for the sample period extending from January 2, 1997 through December 30, 1999:

$C^a + t_c \; - Max\, [\; \lambda(S^b\text{-}D) - K\, exp(-r\tau) - (t_S + t_r\,),\, 0] \geq 0$ (1a)

$P^a + t_p - Max\, [K\, exp(-r\tau) - (S^a\text{-}D) - (t_S + t_r\,),\, 0] \geq 0$ (1b)

The analysis uses intra-day transaction prices for the CAC 40 index European options (PXL contracts) and the intra-day reported quotes of the CAC 40 index level. The 158,253 observations resulted after screening out procedures options transactions with a reported price less than 1 index point and options with maturity less than two days or higher than 180 days.

The statistical significance of the change in the percentage of violations with the shift to the Euro is assessed using a Z-statistic for the difference between two proportions.

	Call Options			Put Options			Total		
	1997-1998	1999	Total	1997-1998	1999	Total	1997-1998	1999	Total
Number of violations	467	215	682	70	55	125	537	270	807
Violation Percentage	1.82	0.41	0.88	0.29	0.10	0.16	1.08	0.25	0.51
|Z-statistic|	16.03***		–	5.10***		–	16.99***		–
Total Number of Observations	25,695	52,232	77,927	23,836	56,490	80,326	49,531	108,722	158,253

Asterisks *, **, *** denote significance at the 10%, 5%, 1% levels respectively.

Table 3: Violations of Put-call Parity

Table 3 reports the number and the percentage of violation of the put-call parity, as well as the mean and the standard deviation of arbitrage profit (in index points), before (1997-1998) and after (1999) the shift to the Euro. The sample period extends from January 2, 1997 through December 30, 1999. The analysis uses intra-day transaction prices for the CAC 40 index European options (PXL contracts) and the intra-day reported quotes of the CAC 40 index level. Options transactions with a reported price less than 1 index point and options with maturity less than two days or higher than 180 days are screened out. Further, the prices are required to be within one minute of each other .

The statistical significance of the change in the percentage of violations with the shift to the Euro is assessed using a Z-statistic for the difference between two proportions. When the number of violations is large, the statistical significance of the difference in volume when violations occur is assessed using a T-statistic for the difference between two means. Mean volume spread is computed as the overall mean volume minus the mean volume when a violation occurs.

Panel A documents the results obtained with equation *(2a)* while *Panel B* uses equation (*2b)*:

$[C^a + K\,exp(-rt)] - [P^b + \lambda(S^b\text{-}D)] + (t_c+t_p+t_S+t_r) \geq 0$ (2a)

$[P^a + (S^a\text{-}D)] - [C^b + K\,exp(-rt)] + (t_c+t_p+t_S+t_r) \geq 0$ (2b)

The four *scenarios* differ in terms of assumptions about the transaction costs and short-selling constraint.

Scen-ario	Option Bid-Ask Spread as % of Transaction Price	Option Trading Exchange Fee (t_c, t_p): Fixed Index Points+ % of Contract Value	Index Bid-Ask Spread as % of Index Level	Index Replication Cost (t_S) (in Index Points)	Short-Sale Proceeds% (λ)
1	0.0	0.000+0.0	0.00	0.0	100
2	1.0	0.000+0.0	0.10	0.0	100
3	1.0	0.025+0.2	0.10	5.0	99
4	2.5	1.000+1.0	0.25	5.0	99

	Scenario 1			*Scenario 2*			*Scenario 3*			*Scenario 4*		
	1997-1998	1999	Total	1997-1998	1999	Total	1997-1998	1999	Total	1997-1998	1999	Total
Panel A												
No. violations	693	917	1,610	393	487	880	139	81	220	35	0	35
Percentage	56.90	58.71	57.91	32.27	31.18	31.65	11.41	5.19	7.91	2.87	0.00	1.26
|Z-statistic|	0.9586		–	0.6124		–	5.8130***		–	5.9991***		–
Mean	18.82	15.83	17.13	24.99	19.50	21.95	16.79	12.46	15.19	4.57	0.00	4.57
Std	22.01	20.71	21.32	22.16	21.81	22.12	10.49	10.40	10.64	4.62	0.00	4.62
Mean vol. Spread	-9.09	-76.16	–	4.77	-191.8	–	4.88	-754.9	–	6.32	–	–
|T-statistic|	0.94	1.40	–	0.37	2.24**	–	0.52	3.55***	–	0.40	–	–
No. obs.	1,218	1,562	2,780	1,218	1,562	2,780	1,218	1,562	2,780	1,218	1,562	2,780
Panel B												
No. violations	525	645	1,170	195	267	462	35	79	114	0	1	1
Percentage	43.10	41.29	42,09	16.01	17.09	16.62	2.87	5.05	4.10	0.00	0.06	0.04
|Z-statistic|	0.9586		–	0.7616		–	2.9781***		–	0.9684		–
Mean	5.04	6.59	5.89	3.71	5.05	4.49	4.51	5.24	5.02	0.00	7.37	7.37
Std	4.49	5.74	5.27	4.36	5.32	4.98	6.12	6.14	6.11	0.00	0.00	0.00
Mean vol. Spread	12.00	108.29	–	17.16	155.84	–	24.91	144.17	–	–	–	–
|T-statistic|	1.79*	2.91***	–	1.98**	3.93***	–	1.59	2.64***	–	–	–	–
No. obs.	1,218	1,562	2,780	1,218	1,562	2,780	1,218	1,562	2,780	1,218	1,562	2,780

Asterisks *, **, *** denote significance at the 10%, 5%, 1% levels respectively.

Table 4: *Ex-ante* Violations of Put-call Parity

Table 4 reports the number and the percentage of ex-ante violation of put-call parity, as well as the mean and the standard deviation of arbitrage profit (in index points), before (1997-1998) and after (1999) the shift to the Euro. The sample period extends from January 2, 1997 through December 30, 1999. The analysis uses intra-day transaction prices for the CAC 40 index European options (PXL contracts) and the intra-day reported quotes of the CAC 40 index level. Options transactions with a reported price less than 1 index point and options with maturity less than two days or higher than 180 days are screened out. Further, the prices are required to be within one minute of each other .

Ex-ante tests are conducted as follows: first, a violation is identified; second, a short or a long hedge is constructed with the next available transaction prices in an interval that does not exceed 15 minutes from the time of identification of the violation. *Percentage (a)* is the ratio of the number of *ex-ante* violations to the total number of observations. *Percentage (b)* is the ratio of the number of *ex-ante* violations to the number of observations available *ex-ante.*

The statistical significance of the change in the percentage of violations with the shift to the Euro is assessed using a Z-statistic for the difference between two proportions. When the number of violations is large, the statistical significance of the difference in volume when violations occur is assessed using a T-statistic for the difference between two means. Mean volume spread is computed as the overall mean volume minus the mean volume when a violation occurs.

Panel A documents the results obtained with equation *(2a)* while *Panel B* uses equation *(2b):*

$$[C^a + K\exp(-rt)] - [P^b + l(S^b - D)] + (t_c + t_p + t_S + t_r) \geq 0 \qquad (2a)$$

$$[P^a + (S^a - D)] - [C^b + K\exp(-rt)] + (t_c + t_p + t_S + t_r) \geq 0 \qquad (2b)$$

The four *scenarios* differ in terms of assumptions about the transaction costs and short-selling constraint .

Scen-ario	Option Bid-Ask Spread as % of Transaction Price	Option Trading Exchange Fee (t_c, t_p): Fixed Index Points+ % of Contract Value	Index Bid-Ask Spread as % of Index Level	Index Replication Cost (t_S) (in Index Points)	Short-Sale Proceeds% (l)
1	0.0	0.000+0.0	0.00	0.0	100
2	1.0	0.000+0.0	0.10	0.0	100
3	1.0	0.025+0.2	0.10	5.0	99
4	2.5	1.000+1.0	0.25	5.0	99

	Scenario 1			*Scenario 2*			*Scenario 3*			*Scenario 4*		
	1997-1998	1999	Total	1997-1998	1999	Total	1997-1998	1999	Total	1997-1998	1999	Total
Panel A												
No. violations	80	75	155	53	33	86	22	10	32	11	0	11
Percentage (a)	6.57	4.80	5.58	4.35	2.11	3.09	1.81	0.64	1.15	0.90	0.00	0.40
|Z-statistic|	1.9832**		–	3.2541***		–	2.7083***		–	–		–
Percentage (b)	88.89	85.23	87.08	86.88	82.50	85.14	88.00	100.00	91.43	100.00	0.00	100.00
Mean	24.13	17.99	21.16	29.34	27.79	28.75	19.21	18.94	19.13	4.39	0.00	4.39
Std	23.99	25.95	25.07	22.67	28.95	25.11	12.50	10.74	11.80	2.39	0.00	2.39
Mean vol. Spread	-4.03	10.22	–	-6.49	-121.1	–	-12.07	–	–	–	0.00	–
|T-statistic|	0.22	0.07	–	0.24	0.54	–	0.23	–	–	–	0.00	–
No. obs.	90	88	178	61	40	101	25	10	35	11	0	11
Panel B												
No. violations	33	48	81	3	22	25	0	4	4	0	0	0
Percentage (a)	2.71	3.07	2.91	0.25	1.41	0.90	0.00	0.26	0.14	0.00	0.00	0.00
|Z-statistic|	0.5643		–	3.5060		–	2.0179		–			–
Percentage (b)	66	73.85	70.43	17.64	61.11	47.17	0.00	33.33	30.77	0.00	0.00	0.00
Mean	5.03	7.90	6.73	5.14	7.02	6.80	0.00	6.32	6.32	0.00	0.00	0.00
Std	3.36	6.22	5.41	4.49	4.99	4.89	0.00	8.53	8.53	0.00	0.00	0.00
Mean vol. Spread	-8.29	-42.85	–	–	-112.5	–	0.00	–	–	0.00	0.00	0.00
|T-statistic|	0.69	0.54	–	–	0.91	–	–	–	–	–	–	–
No. obs.	50	65	115	17	36	53	1	12	13	0	0	0

Asterisks *, **, *** denote significance at the 10%, 5%, 1% levels respectively.

Table 5: Violations of Put-call Parity by Moneyness and Time to Maturity

Table 5 reports the number and the percentage (in parentheses) of violation of the put-call parity, as well as the mean (in bracket) and the standard deviation (in curly bracket) of arbitrage profit (in index points) for options of different moneyness and time to maturity. The results presented here are for Scenario 1 where bid-ask spread, exchange fees and short sale constraint are ignored. The sample period extends from January 2, 1997 through December 30, 1999. The analysis uses intra-day transaction prices for the CAC 40 index European options (PXL contracts) and the intra-day reported quotes of the CAC 40 index level. Options transactions with a reported price less than 1 index point and options with maturity less than two days or higher than 180 days are screened out. Further, the prices are required to be within one minute of each other .

Panel A documents the results obtained with equation *(2a)* while *Panel B* uses equation (*2b*):

$[C^a + K\,exp(-rt)] - [P^b + l(S^b\text{-}D)] + (t_c+t_p+t_S+t_r)$ ³ 0 (2a)

$[P^a + (S^a\text{-}D)] - [C^b + K\,exp(-rt)] + (t_c+t_p+t_S+t_r)$ ³ 0 (2b)

	Short-term		Medium-term		Long-term	
	2 < Days-to-expiration ≤ 90		90 < Days-to-expiration ≤ 120		120 < Days-to-expiration ≤ 180	
Scenario	*Ex-Post*	*Ex-Ante*	*Ex-Post*	*Ex-Ante*	*Ex-Post*	*Ex-Ante*
Panel A						
Out-of-the-money (OTM)	31	2	5	0	21	1
	59.62	50.00	71.42	-	70.00	100.00
	6.02	2.29	13.95	-	35.18	97.78
	4.51	1.31	12.98	-	30.66	-
S/K <0.95						
At-the-money (ATM)	829	63	245	33	164	30
	49.94	80.77	76.08	97.05	91.11	100.00
	8.45	7.12	19.25	11.86	52.48	57.01
	9.19	6.70	21.14	19.87	23.77	18.21
0.95< *S/K* <1.05						
In-the-money (ITM)	90	5	121	5	87	12
	41.09	83.33	62.05	55.55	91.58	100.00
	6.54	4.13	11.38	12.80	46.61	42.04
	9.83	3.07	13.26	10.96	21.05	17.13
S/K >1.05						
Panel B						
Out-of-the-money (OTM)	21	0	2	0	9	0
	40.38	-	28.57	-	30.00	-
	4.22	-	1.18	-	9.78	-
	3.49	-	1.25	-	14.19	-
S/K <0.95						
At-the-money (ATM)	831	66	77	3	16	0
	50.06	75.86	23.91	37.50	8.89	-
	6.16	6.86	4.82	2.58	8.23	-
	5.32	5.64	3.73	2.01	9.47	-
0.95< *S/K* <1.05						
In-the-money (ITM)	129	5	74	2	8	1
	58.90	71.43	37.95	50.00	8.42	100.00
	5.30	8.90	4.78	5.17	6.00	8.07
	4.47	4.28	4.27	6.93	4.65	-
S/K >1.05						

Table 6: Violations of Call and Put Spreads

Table 6 reports the number and the percentage of violations of call and put spread, as well as the mean and the standard deviation of arbitrage profit (in index points), before (1997-1998) and after (1999) the shift to the Euro. The sample period extends from January 2, 1997 through December 30, 1999. The analysis uses intra-day transaction prices for the CAC 40 index European options (PXL contracts) and the intra-day reported quotes of the CAC 40 index level. Options transactions with a reported price less than 1 index point and options with maturity less than two days or higher than 180 days are screened out. Further, the prices are required to be within one minute of each other .

The statistical significance of the change in the percentage of violations with the shift to the Euro is assessed using a Z-statistic for the difference between two proportions.

The results are obtained from equation *(3a)* for call options and from equation *(3b)* for put options:

$$(C_2^a - C_1^b) + (K_2 - K_1)\exp(-r\tau) + (2t_c + t_r) \geq 0 \qquad (3a)$$

$$(P_1^a - P_2^b) + (K_2 - K_1)\exp(-r\tau) + (2t_p + t_r) \geq 0 \qquad (3b)$$

The four *scenarios* differ in terms of assumptions about the transaction costs and short-selling constraint.

Scen-ario	Option Bid-Ask Spread as % of Transaction Price	Option Trading Exchange Fee (t_c, t_p): Fixed Index Points+ % of Contract Value	Index Bid-Ask Spread as % of Index Level	Index Replication Cost (t_S) (in Index Points)	Short-Sale Proceeds% (l)
1	0.0	0.000+0.0	0.00	0.0	100
2	1.0	0.000+0.0	0.10	0.0	100
3	1.0	0.025+0.2	0.10	5.0	99
4	2.5	1.000+1.0	0.25	5.0	99

	Scenario 1			*Scenario 2*			*Scenario 3*			*Scenario 4*		
	1997-1998	1999	Total	1997-1998	1999	Total	1997-1998	1999	Total	1997-1998	1999	Total
Call												
No. violations	57	27	84	3	1	4	2	1	3	0	0	0
Percentage	0.66	0.16	0.34	0.03	0.01	0.02	0.02	0.01	0.01	0.00	0.00	0.00
|Z-statistic|	5.3864***		–	0.9869		–	0.5829		–	–		–
Mean	2.20	1.93	2.11	8.92	16.09	10.71	11.09	13.33	11.84	0.00	0.00	0.00
Std	4.50	5.21	4.71	11.29	0.00	9.90	11.46	0.00	8.20	0.00	0.00	0.00
No. obs.	8,589	16,248	24,837	8,589	16,248	24,837	8,589	16,248	24,837	8,589	16,248	24,837
Put												
No. violations	1	3	4	0	2	2	0	2	2	0	1	1
Percentage	0.01	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.00	0.00
|Z-statistic|	0.0000		–	0.8804		–	0.8804		–	–		–
Mean	0.09	13.27	9.98	0.00	17.20	17.20	0.00	16.17	16.17	0.00	9.99	9.99
Std	0.00	19.04	16.88	0.00	19.85	19.85	0.00	19.52	19.52	0.00	0.00	0.00
No. obs.	7,751	20,157	27,908	7,751	20,157	27,908	7,751	20,157	27,908	7,751	20,157	27,908

Asterisks *, **, *** denote significance at the 10%, 5%, 1% levels respectively.

Table 7: Violations of Box Spread

Table 7 reports the number and the percentage of violations of box spread, as well as the mean and the standard deviation of arbitrage profit (in index points), before (1997-1998) and after (1999) the shift to the Euro. The sample period extends from January 2, 1997 through December 30, 1999. The analysis uses intra-day transaction prices for the CAC 40 index European options (PXL contracts) and the intra-day reported quotes of the CAC 40 index level. Options transactions with a reported price less than 1 index point and options with maturity less than two days or higher than 180 days are screened out. Further, the prices are required to be within one minute of each other .

The results are obtained using equation *(4a)* in *Panel A* and using equation *(4b)* in *Panel B*:

$(C_1^a - C_2^b) - (P_1^b - P_2^a) + (K_1 - K_2)\, exp(-r\ t) + (2t_c+2t_p+t_r)$ ³ 0   (4a)

$(C_2^a - C_1^b) - (P_2^b - P_1^a) + (K_2 - K_1)\, exp(-r\ t) + (2t_c+2t_p+t_r)$ ³ 0 (4a)

The statistical significance of the change in the percentage of violations with the shift to the Euro is assessed using a Z-statistic for the difference between two proportions. When the number of violations is large, the statistical significance of the difference in volume when violations occur is assessed using a T-statistic for the difference between two means. Mean volume spread is computed as the overall mean volume minus the mean volume when a violation occurs.

The four *scenarios* differ in terms of assumptions about the transaction costs and short-selling constraint.

Scen-ario	Option Bid-Ask Spread as % of Transaction Price	Option Trading Exchange Fee (t_c, t_p): Fixed Index Points+ % of Contract Value	Index Bid-Ask Spread as % of Index Level	Index Replication Cost (t_S) (in Index Points)	Short-Sale Proceeds% (*l*)
1	0.0	0.000+0.0	0.00	0.0	100
2	1.0	0.000+0.0	0.10	0.0	100
3	1.0	0.025+0.2	0.10	5.0	99
4	2.5	1.000+1.0	0.25	5.0	99

	Scenario 1			*Scenario 2*			*Scenario 3*			*Scenario 4*		
	1997-1998	1999	Total	1997-1998	1999	Total	1997-1998	1999	Total	1997-1998	1999	Total
Panel A												
No. violations	17	76	93	2	26	28	0	21	21	0	0	0
Percentage	40.48	43.93	43.26	4.76	15.03	13.02	0.00	12.14	9.76	0.00	0.00	0.00
|Z-statistic|	0.4077		–	2.4089**		–	4.8892***		–		–	–
Mean	2.33	2.73	2.65	1.33	3.00	2.89	0.00	2.07	2.07	0.00	0.00	0.00
Std	3.01	2.87	2.88	0.33	2.41	2.36	0.00	2.24	2.24	0.00	0.00	0.00
Mean vol. Spread	72.17	-18.5	–	–	-53.29	–	0.00	-64.63	–	0.00	0.00	0.00
|T-statistic|	0.61	0.47	–	–	1.35	–	–	1.72*	–	–	–	–
No. obs.	42	173	215	42	173	215	42	173	215	42	173	215
Panel B												
No. violations	25	97	122	2	22	24	0	16	16	0	0	0
Percentage	59.52	56.07	56.74	4.76	12.72	11.16	0.00	9.25	7.44	0.00	0.00	0.00
|Z-statistic|	0.4077		–	1.9187**		–	4.1992***		–		–	–
Mean	2.30	3.16	2.98	1.51	4.32	4.08	0.00	3.64	3.64	0.00	0.00	0.00
Std	2.27	4.27	3.95	0.00	4.57	4.45	0.00	4.87	4.87	0.00	0.00	0.00
Mean vol. spread	-48.74	14.49	–	–	-132.4	–	0.00	-125.1	–	0.00	0.00	0.00
|T-statistic|	0.41	0.46	–	–	1.24	–	–	1.03	–	–	–	–
No. obs.	42	173	215	42	173	215	42	173	215	42	173	215

Asterisks *, **, *** denote significance at the 10%, 5%, 1% levels respectively.

Table 8: Violations of Call and Put Convexity

Table 8 reports the number and the percentage of violations of call and put convexity, as well as the mean and the standard deviation of arbitrage profit (in index points), before (1997-1998) and after (1999) the shift to the Euro. The sample period extends from January 2, 1997 through December 30, 1999. The analysis uses intra-day transaction prices for the CAC 40 index European options (PXL contracts) and the intra-day reported quotes of the CAC 40 index level. Options transactions with a reported price less than 1 index point and options with maturity less than two days or higher than 180 days are screened out. Further, the prices are required to be within one minute of each other .

The results are obtained from equation *(5a)* for call options and from equation *(5b)* for put options:

$wC_1^a + (1\text{-}w)C_3^a - C_2^b + 3t_c \geq 0$ (5a)

$wP_1^a + (1\text{-}w)P_3^a - P_2^b + 3t_p \geq 0$ (5b)

with $w = (K_3 - K_2) / (K_3 - K_1)$.

The statistical significance of the change in the percentage of violations with the shift to the Euro is assessed using a Z-statistic for the difference between two proportions. When the number of violations is large, the statistical significance of the difference in volume when violations occur is assessed using a T-statistic for the difference between two means. Mean volume spread is computed as the overall mean volume minus the mean volume when a violation occurs.

The four *scenarios* differ in terms of assumptions about the transaction costs and short-selling constraint.

Scen-ario	Option Bid-Ask Spread as % of Transaction Price	Option Trading Exchange Fee (t_c, t_p): Fixed Index Points+ % of Contract Value	Index Bid-Ask Spread as % of Index Level	Index Replication Cost (t_S) (in Index Points)	Short-Sale Proceeds% (l)
1	0.0	0.000+0.0	0.00	0.0	100
2	1.0	0.000+0.0	0.10	0.0	100
3	1.0	0.025+0.2	0.10	5.0	99
4	2.5	1.000+1.0	0.25	5.0	99

	Scenario 1			*Scenario 2*			*Scenario 3*			*Scenario 4*		
	1997-1998	1999	Total	1997-1998	1999	Total	1997-1998	1999	Total	1997-1998	1999	Total
Call												
No. violations	13	283	296	5	96	101	3	49	52	0	0	0
Percentage	0.37	1.51	1.34	0.14	0.51	0.46	0.09	0.26	0.23	0.00	0.00	0.00
|Z-statistic|	8.3660***		–	4.5071***		–	2.6961***		–	–		–
Mean	2.18	1.51	1.54	3.37	1.47	1.57	4.35	1.23	1.40	0.00	0.00	0.00
Std	2.60	1.96	2.00	3.17	1.93	2.03	2.24	2.01	2.13	0.00	0.00	0.00
Mean vol. Spread	25.22	41.99	–	–	-1.64	–	–	14.19	–	0.00	0.00	0.00
|T-statistic|	4.57***	1.76*	–	–	0.01	–	–	0.20	–	–	–	–
No. obs.	3,474	18,690	22,164	3,474	18,690	22,164	3,474	18,690	22,164	3,474	18,690	22,164
Put												
No. violations	77	695	772	64	299	363	50	111	161	17	1	18
Percentage	2.14	2.52	2.47	1.78	1.08	1.16	1.39	0.40	0.52	0.47	0.00	0.06
|Z-statistic|	1.4667		–	3.0557***		–	4.9781***		–	4.1214***		–
Mean	9.43	1.36	2.16	9.03	1.18	2.56	9.94	1.39	4.05	7.43	5.69	7.33
Std	10.17	1.63	4.29	9.53	1.55	5.17	9.41	1.82	6.72	2.68	0.00	2.63
Mean vol. Spread	35.55	40.49	–	37.08	71.97	–	34.81	53.38	–	59.18	–	–
|T-statistic|	3.66***	2.39***	–	3.52***	3.92***	–	2.66***	1.69*	–	16.9***	–	–
No. obs.	3,597	27,597	31,194	3,597	27,597	31,194	3,597	27,597	31,194	3,597	27,597	31,194

Asterisks *, **, *** denote significance at the 10%, 5%, 1% levels respectively.

APPENDIX A: CAC 40 Index: Stocks, Weighting and Business Sectors (as of September 10, 1999) [Source: *EuroNext* Paris]

Company	Weight (in %)	Cumulative Weight in (%)	Market Capitalization (in EUR millions)	Business Sector
France Télécom	10.07	10.07	79,049	Capital equipment
ELF Aquitaine	6.38	16.45	50,055	Energy
Total Fina	5.79	22.24	45,423	Energy
AXA	5.29	27.53	41,614	Financial institution
Vivendi	5.25	32.78	41,157	Other services
L'Oréal	5.20	37.98	40,766	Consumer goods
Carrefour	4.67	42.65	36,638	Retailers
BNP	3.77	46.42	29,547	Financial institution
Alcatel	3.61	50.03	28,316	Capital equipment
LVMH Moët-Vuitton	3.59	53.62	28,165	Food & Beverages
Sanofi-Synthelabo	3.54	57.16	27,791	Consumer goods
Suez-Lyonnaise des Eaux	3.02	60.18	23,693	Other services
Pinault Printemps Redoute	2.67	62.85	20,950	Retailers
Stmicroelectronics NV	2.65	65.50	20,823	Capital equipment
Société Générale	2.60	68.10	20,378	Financial institution
Rhône-Poulenc	2.29	70.39	17,956	Consumer goods
Danone	2.22	72.61	17,425	Food & Beverages
Promodès	2.20	74.81	17,249	Retailers
Equant	2.12	76.93	16,621	Capital equipment
Saint-Gobain	2.06	78.99	16,143	Construction
Cap Gémini	1.80	80.79	14,100	Other services
Renault	1.65	82.44	12,925	Automobile
Air Liquide	1.60	84.04	12,541	Basic materials
Lafargue	1.43	85.47	11,203	Construction
Schneider Electric	1.42	86.89	11,167	Capital equipment
Peugeot	1.23	88.12	9,673	Automobile
Crédit Lyonnais	1.18	89.30	9,270	Financial institution
AGF	1.15	90.45	9,049	Financial institution
CCF	1.14	91.59	8,953	Financial institution
Canal+	1.11	92.70	7,719	Other services
Accor	1.00	93.70	7,862	Other services
Casino Guichard	0.97	94.67	7,603	Retailers
Valéo	0.83	95.50	6,492	Automobile
Michelin "B"	0.81	96.31	6,390	Automobile
Thomson CSF	0.74	97.05	5,786	Capital equipment
Dexia France	0.66	97.71	5,145	Financial institution
Sodhexo-Alliance	0.66	98.37	5,153	Other services
Lagardère	0.64	99.01	4,996	Investment company
Legrand	0.59	99.60	4,690	Capital equipment
Eridania Beghin	0.40	100.00	3,222	Food & Beverages

APPENDIX B: Steps in Identifying Arbitrage Violation and Trading

In this appendix, we use hypothetical examples to illustrate how we identify a violation for each arbitrage condition under study and how trading is implemented in the *ex-ante* tests.

Ex-post Test of Lower Boundary Condition

This case is illustrated for the boundary condition *(1a)*:

$$C^a + t_c - Max\,[\,\lambda(S^b - D) - K\,exp(-r\tau) - (t_S + t_r),\, 0] \geq 0$$

Suppose our record shows an option transaction at 1:00 PM for a call option with strike K and time to maturity of τ days at a price of C. We find the quote for the CAC 40 Index nearest to 1:00 PM. This may be before or after 1:00 PM. However, the difference between options transaction time and the index quote time is always under thirty seconds as the index quote is updated every thirty seconds. As we do not have information about the bid and ask of the index or the option prices, we simply use the prices as per quote of the index and transaction for the option in testing all the conditions in this paper.

Ex-post and *Ex-ante* Tests of the Put Call Parity (PCP) Condition

This case is illustrated for the boundary condition *(2a)*:

$$[C^a + K\,exp(-r\tau)] - [P^b + \lambda(S^b - D)] + (t_c + t_p + t_S + t_r) \geq 0$$

Suppose our record shows an option transaction at 1:00 PM for a call option with strike K and time to maturity of τ days at a price of C. Next we examine if there is a transaction for a put option with the same strike and maturity date within the next minute, i.e., at or before 1:01 PM. The quote for the CAC 40 Index nearest to 1:00 PM is then located. The difference between call option and put option transaction times is always under one minute. The time of the index quote time is always under 30 seconds from the recorded time of the first of the two (call and put) option transactions and under 90 seconds from the recorded time of the last of the two (call and put) option transactions.

The call and put option transaction prices (C_i and P_i) and the index quote (S_i) noted are used to calculate the left hand side of equation *(2a)*. If a negative number is found, it is identified as an *ex-post* violation of the arbitrage condition *(2a)*. The absolute magnitude of the number is treated as the level (in Euro) of arbitrage violation or ex-post arbitrage profit.

Say, for the set of call and put option transaction prices and the index option quote just noted, we find the arbitrage condition *(2a)* is violated. We then locate the next available pair of transactions, traded within one minute of each other, for the same set of call and put options. If this second set of options transactions take place within 15 minutes from 1:00 PM (the recorded time of transaction for the call/put options in the first set), say at 1:07 PM and 1:08 PM, we use the second set of options transaction prices (C_{I+1} and P_{I+1}) and the index quote (S_{i+1}) nearest to 1:07 PM to implement our arbitrage trades. If the net cashflow from the arbitrage trades is positive (that is if the left hand side of *(2a)* is still negative using the second set of prices), it is identified as an *ex-ante* violation of the PCP condition *(2a)* and the absolute value of the left hand side is taken to be the *ex-ante* arbitrage profit or level of violation.

Ex-post Tests of Call and Put Spreads

This case is illustrated for the call spread arbitrage condition *(3a)*:

$$(C_2^a - C_1^b) + (K_2 - K_1)\, exp(-r\, t) + (2t_c + t_r) \geq 0$$

Suppose our record shows an option transaction at 1:00 PM for a call option with strike K_1 and time to maturity of t days at a price of C_1. We examine whether there is a transaction for a call option with a different strike K_2 and the same maturity date within one minute interval (i.e. at or before 1:01 PM). Then, we use the transaction prices (C_2 and C_1) located to calculate the left hand side of the condition *(3a)*. If the calculated number is negative, it is identified as an ex-post violation of *(3a)* and the absolute value is used as the arbitrage profit or level of violation.

Ex-post Tests of Box Spread

This case is illustrated for the box spread arbitrage condition *(4a)*:

$$(C_1^a - C_2^b) - (P_1^b - P_2^a) + (K_1 - K_2)\, exp(-r\, t) + (2t_c + 2t_p + t_r) \geq 0$$

Suppose our record shows an option transaction at 1:00 PM for a call option with strike K_1 and time to maturity of t days at a price of C_1. We examine whether within one minute interval (i.e. at or before 1:01 PM) there is a transaction for a call option with strike K_2 and a put option transaction with strike K_1, and another put option transaction with strike K_2, all options sharing the same maturity date t. The transcription prices (C_1, C_2, P_1 and P_2) located are then used to calculate the left hand side of the condition *(4a)*. If the calculated number is negative, it is identified as an ex-post violation of *(4a)* and the absolute value is used as the arbitrage profit or level of violation.

Ex-post **Tests of Convexity (Butterfly Spread)**

This case is illustrated for the call option convexity condition *(5a)*:

$$wC_1^a + (1-w)C_3^a - C_2^b + 3t_c \geq 0$$

Suppose our record shows an option transaction at 1:00 PM for a call option with strike K_1 and time to maturity of t days at a price of C_1. We examine whether within one minute interval (i.e. at or before 1:01 PM) there is a transaction for a call option with strike and a call option transaction with strike K_3, all options sharing the same maturity date t. We then use the transaction prices (C_1, C_3 and C_2) located to calculate the left hand side of the condition *(5a)*. If the calculated number is negative, it is identified as an ex-post violation of *(5a)* and the absolute value is used as the arbitrage profit or level of violation.