The Introduction of the CAC40 Master Unit and the CAC40 Index Spot-Futures Pricing Relationship[1]

Laurent Deville
Paris-Dauphine University, CNRS, DRM-CEREG
Laurent.Deville@dauphine.fr

Carole Gresse[2]
Paris-Dauphine University, DRM-CEREG and Paris-Nanterre University, CEROS
carole.gresse@u-paris10.fr

Béatrice de Séverac
Paris-Nanterre University, CEROS
bseverac@u-paris10.fr

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[1] The authors gratefully acknowledge the financial support of the Europlace Institute of Finance.
[2] Corresponding author: Carole Gresse – Université Paris-Dauphine – DRM-CEREG – place du Ml de Lattre de Tassigny – 75775 Paris cedex 16 – France. E-mail at carole.gresse@u-paris10.fr.

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Abstract

Our article investigates the impact of the introduction of the CAC40 Master Unit ETF on the cash-futures pricing relationship between the CAC40 futures contract and its underlying index. Using tick-by-tick CAC40 futures data and 30-s interval data for the CAC40 index, we not only analyse deviations from no-arbitrage prices but also time to efficiency. We find evidence of a significant reduction in the frequency of ex post deviations as well as in their size when controlling for volatility, liquidity and dividend delivery. Concerning the speed of price reversion in response to arbitrage opportunities, tests upon ex ante arbitrage profits and time to efficiency show an efficiency improvement for sell arbitrages only.

1. Introduction

The number of index-based securities, known as Exchange Traded Funds (ETFs) or trackers, have exploded since their first introduction in the 90s on the Canadian and US equity markets. They emerged in Europe in 2000 when the Frankfort and the London stock exchanges opened their tracker markets, and their number has increased tremendously ever since. ETFs are investment funds designed to replicate an index. These funds are open ended in the sense that their shares may be created and redeemed in very large blocks. Their popularity is assignable to the ease with which they allow any category of investors to obtain portfolio diversification benefits at low trading costs. Their relatively low price per share gives the opportunity to small investors to take positions in an entire index. In such, market efficiency improvements may be expected from their introduction. In particular, given that they replicate baskets of existing securities and that some of these baskets serve as an underlying asset for derivatives, the inception of trackers may have an impact on the joint efficiency of those related markets. Cherry (2004) addresses the issue of the efficiency relationship between ETFs and their underlying indices and finds that ETFs are priced more efficiently priced than close-end funds but still trade away from their net asset value with abnormal discounts considering their transparency[3] and liquidity. Other authors have studied the impact of ETF inception on various no-arbitrage relationships between stock and derivative prices (Ackert and Tian (1998), Deville (2002), Deville and Riva (2005), Kurov and Lasser (2002), Park and Switzer (1995), Switzer *et al*. (2000)). The present paper tests whether the creation of stocks tracking the CAC40 index improved the well-known no cash-and-carry (or no reverse cash-and-carry) arbitrage relationship between the spot prices of CAC40 components and the CAC40 futures contract prices. To this aim, we exploit tick-by-tick futures data and intra-day index values, and we compare the frequency, the magnitude and the speed of reversion of efficiency violations six months before and six months after January 22nd, 2001, date of the CAC40 Master Unit inception.

An extensive literature (e.g. Modest and Sundaresan (1983), Figlewski (1984), MacKinlay and Ramaswamy (1988), Yadav and Pope (1994)) suggest that significant deviations from the cash-futures no arbitrage relationship with potential profits for arbitrageurs exist in index futures markets. Chung (1991), Klemkosky and Lee (1991) and

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[3] ETFs' portfolios are extremely transparent since their composition are published daily.

Miller *et al*. (1994) argue that these deviations are more probably the reflection of transactions costs, market non-synchronicity or market illiquidity, than exploitable profits. However, recent research by Garrett and Taylor (2000), Tse (2000) and Alphonse (2003) shows that arbitrage activity drives, at least partially, mean reversion in futures mispricing. The main difficulty that arbitrageurs face in index cash-futures arbitrages is to establish the cash leg. Implicit transaction costs, non-synchronicity, price risk due to intra-day volatility when trading the stock basket, are as many factors that reduce considerably arbitrage profits. Because basket securities lower these frictions as shown by Hegde and McDermott (2004), they have been proved to tighten the cash-futures relationship in the case of the Toronto 35 index (Park and Switzer (1995)), the Standard&Poor's 500 Composite index (Switzer et al. (2000)) and the NASDAQ-100 (Kurov and Lasser (2002)). We check whether the introduction of the CAC40 Master Unit had the same impact on the French market, which has not been done at the current date. Like Kurov and Lasser (2002), we use the most accurate high frequency data that are available for the futures contract and the index. Further, we improve the analysis in several respects. First, in our comparison of ex post and ex ante deviations, we control not only for intraday index volatility but also for actual implicit costs in the CAC40 stocks and CAC40 trading volumes. Second, and more importantly, we measure and analyse the durations of deviation reversions. Classical tests of futures market pricing efficiency essentially focus on the deviations' values rather than on their persistence in time. Nevertheless, it is argued that ETF trading should induce a quicker reversion of futures prices towards no-arbitrage values because arbitrageurs are able to establish their portfolios more rapidly. Tests on ex ante arbitrage profits are a means to explore this hypothesis but we consider they are insufficient in that they are based on arbitrary lags of arbitrage execution. Therefore, we realise tests on the time to efficiency, that is the actual duration of a deviation before reversion.

The remainder of the article is organised as follows. Section 2 presents the theoretical hypotheses tested in the paper. Section 3 describes the data and the calculation of ex post and ex ante deviations from no-arbitrage prices. Section 4 reports our findings on the pre-/post-ETF comparison of mispricing and arbitrage profits, and provides a time-series analysis of mispricing levels. Section 5 examines the impact of the ETF introduction on time to efficiency. Section 6 concludes.

2. Testable hypotheses on the spot-futures pricing relationship and the introduction of ETFs

In the absence of arbitrage opportunities, the cost-of-carry model holds and the theoretical price of a index futures contract is given by:

$$F_{t,T}^{*} = \left(I_t - D_{t,T}\right) e^{r(T-t)} \quad (1),$$

where I_t is the value of the index at time t; r the risk-free interest rate; $D_{t,T}$ the present value, expressed in index points, of the dividends delivered by the index stocks in the period t-T; and T the futures maturity. Any deviation of market futures prices from this theoretical value is considered as mispricing. Following most studies on futures market efficiency, we define the ex post mispricing in the futures contract as:

$$\left|x_{t,T}\right| = \frac{\left|F_{t,T}^{*} - F_{t,T}\right|}{I_t} \quad (2),$$

where F_t is the actual futures price at time t for maturity T.

The rationale for this formula is the possibility to replicate the futures cash-flows by taking adequate positions in the stock basket constituting the index and the interest rate. For futures price inferior to the theoretical value, a rational arbitrageur makes a risk-free profit by implementing a short or sell arbitrage, that is taking a short position in the index portfolio and buying the futures contract. Conversely, when the market futures price is superior to the fair value, arbitrages that consist in buying the index portfolio and selling the futures contract, usually designated as long or buy arbitrages, are profitable strategies. In each case, arbitrage trades will continue until the pressure onto prices is such that they revert to values compatible with the no-arbitrage theory.

However, arbitrage execution is costly. Under the assumption that there exists no restriction on trading, arbitrage models predict that arbitrage portfolios will be established as soon as the difference between the theoretical futures price and the market futures price is larger than the transaction costs incurred for the establishment of the arbitrage portfolio. Hence, costs form bounds inside which futures prices can fluctuate without triggering arbitrage-oriented trades. An arbitrage profit $\pi_{t,T}$ is then equal to the mispricing value net of the transaction costs c associated with the trading in the spot and futures markets:

$$\pi_{t,T} = \frac{\left| F^{*}_{t,T} - F_{t,T} \right|}{I_t} - c \qquad (3).$$

A deviation from efficient prices will trigger arbitrage execution only if its value $\left| x_{t,T} \right|$ exceeds c.

Empirical tests on the index spot-futures relationship[4] commonly agree that arbitrage opportunities exist on all markets, even once transaction costs are accounted for but remain small in value. Several explanations for the existence and the persistence of arbitrage opportunities have been proposed: delayed incorporation of new information into prices, noise trading, liquidity risk[5], institutional constraints etc. Among these market frictions, index-tracking risk remains the major obstacle to arbitrage execution. ETFs, which replicate indices accurately, should thus ease the establishment of arbitrage positions at lower costs and risk.

The CAC40 Master Unit was introduced on January 22nd, 2001 on Euronext Nextrack, a market segment specifically dedicated to the negotiation of ETFs on Euronext. Table 1 reports its trading volume for the first six months of trading along with the average trading volume of the CAC40 constituent stocks. In terms of daily euro traded volume, the CAC40 Master Unit ranks 29th within the CAC40 stocks. The number of trades recorded for the ETF is very small compared to genuine stocks, with an average of 219 transactions a day, but trades in the ETF are much larger. On average, more than 150,000 €, representing 4,152 units of trackers, that is 41.52 times the euro-denominated value of the CAC40 index, are traded on each transaction whereas the median trade size for a CAC40 stock only amounts to 32,499 €. Hence, it clearly appears that the market for the CAC40 Master Unit is dominated by institutional traders rather than by individuals. Moreover, the CAC40 Master Unit trading level in its first six months of existence has been significant enough to affect market liquidity and arbitrage activity.

Table 1 about here

Potential effects are diverse but the most likely is undoubtedly the arbitrage hypothesis mentioned by Hegde and McDermott (2004).

[4] For an extensive review on stock index futures studies, see Sutcliffe (1997).

[5] There is a risk of adverse price movements between the detection of an opportunity by arbitrageurs and the moment when their arbitrage portfolios are actually established.

2.1. The arbitrage hypothesis

The findings of Hegde and McDermott (2004) suggest that the arbitrage activity between stock indices, futures and options might have increased with the introduction of ETFs. Assuming that markets are informationally segmented, the introduction of ETFs should improve the efficiency index stock and index futures prices through an increase of arbitrage trading, because it removes some of the obstacles that limit the arbitrageurs' ability to establish their positions. The first testable implication on the introduction of CAC40 Master Unit that tracks the CAC40 index should therefore be a reduction in the frequency and value of deviations as the market should be more closely monitored and arbitrage portfolios should be less costly and risky to implement. However, assuming that tracking risk is the key problem in spot-futures pricing relationship, we should observe more mitigated effects than those observed in previous studies. Obviously, the CAC40 index is less difficult to track than indices that are constituted by a higher number of stocks, like the S&P 500 or the Nasdaq-100 stock index that are the underlying indices of the futures contracts studied by Switzer, Varson and Zghidi (2000) and Kurov and Lasser (2002), respectively.

The arbitrage hypothesis also entails a quicker reversion process when prices deviate from fundamental values. If ETFs effectively ease the construction of arbitrage portfolios, their introduction should result in shorter arbitrage delays, and prices should revert more rapidly to levels that prevent from subsequent arbitrage trades.

Finally, this reduction in deviations may not be symmetric. Actually, sell arbitrages require to sell the underlying index, or more precisely short-sell the index if not previously owned by the arbitrageur. If there are benefits in trading the index through the ETFs rather than through the stock basket, these benefits should be even higher for short-selling. As a result, we should observe a reduction in the value of the deviations to the lower boundary, e.g. the boundary that triggers sell arbitrage trades.

2.2. The liquidity hypothesis

ETFs trade on a continuous market with dedicated market-makers posting firm quotes to the central order book. The introduction of market making on a security replicating the index may add depth to the index stock market and smooth temporary price tensions due to liquidity or noise trading in index components, in particular if noise traders prefer to trade in the ETF market for its lower cost. According to this hypothesis, the launch of the ETF would reduce the probability of no-arbitrage violations but not necessarily shorten the time to efficiency unless the arbitrage hypothesis also holds.

2.3. The adverse selection hypothesis

An alternative hypothesis, modelled by Subramanyam (1991) designated as the adverse selection hypothesis by Hegde and McDermott (2004), relates to the ETF's impact on informed trading. Subramanyam (1991) models the strategic behaviour of traders who can choose to trade either in the basket stock market or in the underlying stock markets. He demonstrates that the basket security market most probably serves as the lowest-cost market for the index. Under this hypothesis, adverse selection costs of component stocks will increase with the tracker's introduction because liquidity traders switch to the ETF market while informed traders remain in the markets for the underlying securities. This decrease in the liquidity of the spot index stock market would then be detrimental to the no-arbitrage spot-futures relationship. With respect to the findings of Hegde and McDermott (2004) and the descriptive statistics on CAC40 stocks' spreads and volumes reported in Table 3, we do not expect this theoretical hypothesis to be validated.

3. Data and mispricing calculations

The results presented in this paper are based on an empirical analysis of the spot-futures pricing relationship for the CAC40 index futures contract for a 12-month period spreading from August 2000 to July 2001. This period surrounds January 22, 2001, the introduction date of the ETF tracking the CAC40 index on NextTrack, which divides our sample into two sub-periods of 121 and 133 trading days, respectively. CAC40 index and futures intraday data are extracted from Euronext Paris Market Database. One week to one year Euribor rates have been retrieved from Thomson Financial Datastream.

3.1. CAC40 futures data

The trading of the futures contract on the CAC40 index (ticker FCE) takes place on the *Marché des Options Négociables de Paris* (MONEP) from 8 am to 5.30 pm on the electronic trading system NSC-VF (day session) and from 5.30 pm to 10 pm on Globex (night session). Since its introduction in 1988, the FCE contract has experienced a tremendous growth in trading volume. In year 2000, it reached a daily average of 71 568 contracts traded. The size of the contract is equal to the value of the CAC40 index multiplied by 10 euros and the tick size is 0.5 index points. Eight maturities (three monthly, three quarterly and two half yearly) are continuously open with a quotation horizon of 19 to 24 months. Settlement is in cash with a liquidation price equal to the arithmetic average (rounded to 1 decimal) of each CAC40 index value calculated and reported on the settlement day between 3:40 pm and 4:00 pm, the first index value after 4:00 pm being included. Summary statistics of the daily activity of the FCE contract both on the pre- and post-introduction period are reported in

Table 2. Trading clearly concentrates on the nearby maturity with an average of more than 10,000 transactions a day for contracts with a maturity of one to two months against less than 1,000 transactions for other maturities. Activity increased after the introduction of the ETF for all maturities except for the two most distant, which is consistent with the growth tendency of the French derivatives market.

Table 2 about here

The Euronext Paris intraday data comprises information for all transactions recorded on the FCE contract. It reports the expiration month, the futures price and the number of contracts traded for each transaction, time-stamped to the nearest second. As it is impossible to match the night-session transactions with contemporaneous index values, they are omitted from the analysis.

3.2. CAC40 index data

The CAC40 index consists of the 40 most actively traded stocks listed on the Main Market of the Paris Stock Exchange, the so-called “Premier Marché”. CAC40 components are selected not only according to liquidity criteria but also in order to be representative of various economic sectors. The CAC40 market value is calculated continuously as the market value weighted average of its 40 constituent stock prices, and disseminated every 30 seconds by Euronext Paris from 9 am to 5.30 pm. The CAC40 index values at 30-s intervals are extracted from the Euronext Paris Market Database.

3.3. Mispricing calculations

To compute the mispricing series, futures prices are associated with the spot index value. Since index futures markets generally lead cash index markets[6], we match futures prices with

[6] Kawaller, Koch and Koch (1988), Stoll and Whaley (1990) or Fleming, Ostdiek and Whaley (1996) show that the S&P 500 futures returns lead the cash index returns by 5 to 45 minutes. On the French market, Shyy, Vijayraghavan and Scott-Quinn (1996) and Alphonse, Capelle-Blancard and Vandelanoite (2001) find evidence that the FCE futures contract leads the CAC40 index. Besides, Sofianos (1993) shows that the futures leg precedes the cash leg when both legs are not established simultaneously.

the index value displayed at the time of the futures transaction or immediately following it. This procedure ensures that no more than 30 seconds elapsed between the two values. This selection process leads to a final sample of 2,927,326 futures prices associated with the prevailing spot index value.

Theoretically, dividends delivered by the index constituent stocks must be accounted for in the derivation of the fair price. Kurov and Lasser (2002) argue that the dividend yield is so low on the Nasdaq-100 index that it can be neglected in the calculations of the theoretical price. Dividends on the French market are usually delivered on an annual basis and highly concentrated around May and June. Hence, ignoring dividends would lead to a potentially severe bias between the pre-introduction sample during which very few dividends have been delivered and the post-introduction sample that encompass dividend-paying months. Discrete dividends have been extracted from Thomson Financial Datastream and expressed in term of CAC40 index points on a daily basis. For each spot-futures pair, the present value of the dividends delivered between the trade and the expiration date of the contract is calculated using Euribor as a proxy for the risk-free interest rate. The interest rate we use as a proxy for the opportunity cost in the calculations is a linear interpolation of the Euribor rates prevailing on the transaction day for maturities surrounding the time to maturity of the FCE contract.

We conduct ex post as well as ex ante tests of the cash-futures relationship. An observation is considered as an ex post deviation from efficient prices when equation (3) leads to a positive value either through the implementation of a sell or a buy arbitrage program.

Ex ante tests consist in reproducing as closely as possible market conditions in order to assess the actual profit accessible to an arbitrageur whose trades are triggered by the observation of an ex post deviation. We compute ex ante profits considering that arbitrage strategies are executed at prices prevailing a few seconds after the observation of a price deviation. We consider several lags from 1 to 3 minutes and draw two main statistics for the whole set of ex post signals over our observation periods: the percentage of lagged strategies leading to positive profits and the average gain/loss resulting from these strategies. Ex ante profits will be positive in the case profits persist long enough or negative if prices revert to no-arbitrage values.

The construction of spot-futures arbitrage strategies requires trading in the underlying stock basket. For the arbitrageurs, it results in different transaction costs, such as commissions and taxes as well as bid-ask spreads, price impacts and, in the case of sell arbitrages, short-selling costs. The transaction costs associated with such trades depends both on market conditions and on orders' aggressiveness. Estimation of such costs for every spot-futures pair identified in your database is not conceivable. However, discussions with professional arbitrageurs have led us to assume the following levels of transaction costs. For the futures contracts, bid-ask spreads are said to be very constant over time at a level of 5 basis points when including explicit costs, so that we charge each FCE contract trade .025%. Concerning the cash market, it is reasonable to assume that, on average, a one-way CAC40 basket trade costs a half bid-ask spread of .125% plus 2 basis points for explicit fees, that is a total cost of .145%. As CAC40 stocks' bid-ask spreads are more volatile that futures spreads, we also apply two other levels of transaction costs for trades on the CAC40 index stock basket: .10% and .15%, i.e. respectively .12% and 17% when adding explicit costs. Expected transaction costs to be supported at the liquidation of the arbitrage portfolios are estimated on the basis on the initial index value. For arbitrage opportunities that require selling the CAC40 index, we consider one additional scheme of transaction costs that includes short-selling costs of .10% supported *pro rata temporis* on the value of the index.

4. Pre- / post-ETF-inception mispricing comparisons

This section presents the empirical results based on pre- / post-introduction of the CAC40 Master Unit comparisons of the spot-futures mispricing series. We first discuss the variation in frequency and value of ex post deviations for different levels of transaction costs. Then, we proceed to pre- and post-ETF ex ante profits, namely profits drawn from arbitrage trades established on the basis of deviation signals and executed with a time lag.

4.1. Ex post deviations

The results of the ex post mispricing tests for all the transactions recorded for the FCE futures contracts from August 2000 to the end of July 2001 are reported in Table 3 for our three different levels of transaction costs. Whatever the transaction costs we assume for the cash leg, there is a highly significant decline in the deviation frequency consecutive to the introduction of ETFs. As an example, for the .125% implicit-cost level, 1.86% of the pairings are outside the no-arbitrage boundaries during the first sample period, a frequency that drops to only .31% once trading in ETFs becomes possible. This finding is consistent with previous evidence by Kurov and Lasser (2002) of a decrease in the deviation frequency of the Nasdaq-100 futures following the introduction of Cubes. The overall deviation frequency is however clearly smaller on the French market since transaction costs of .50% are necessary for Kurov and Lasser to get comparable levels.

Table 3 about here

There is a slight asymmetry in the direction of deviations. Both before and after ETFs inception, sell arbitrages, that are also classically referred to as short arbitrage due to the short position taken in the index portfolio, are predominant, even once short-selling costs are accounting for. Although there is no consensus in previous empirical literature on the direction of deviations, [7] the underpricing of index futures is classically related to restrictions or difficulties in short-selling. Since the improvement is more important for this category of deviations, our results suggest that ETFs actually facilitate the index short-selling.

Results concerning the average absolute level of deviations are more intriguing. Whereas the mispricing frequency strongly decreases following the introduction of ETFs, their average (or median) value, on the contrary, significantly increases.

Our results on ex post profits differ from previous studies mainly in two ways: firstly, deviation frequencies are very low, suggesting that the French market is heavily monitored; secondly, whereas frequencies decrease with the introduction of ETFs, deviation values, on the contrary, increase. One may wonder whether this is explained by the fact that, converse to previous studies, we work with all transactions and maturities, including futures contracts that mature up to one year later. Results are split between two panels in Table 4: panel A reports, with no distinction between buy and sell arbitrages, the results for the nearby maturity while panel B reports the results for all others maturities.

Table 4 about here

The nearby maturity accounts for the majority of trades in FCE contracts. As previously documented by MacKinlay and Ramaswamy (1988), Bhatt and Cakici (1990), Klemkosky and Lee (1991) and Switzer, Varson and Zghidi (2000) on the S&P 500 index futures, maturity appears to be a determinant of the deviation frequency, yet, as surprising as it may seem, it is not the case for deviation values. Results for the nearby maturity are similar to those for the whole sample. More interesting are the results for other maturities. Before the introduction of the CAC40 Master Unit, the deviation frequency for upper maturities is very

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[7] See Sutcliffe (1997) section 5.1.

high, even when transaction costs are accounted for, but this percentage drops twenty fold after the ETF introduction, to reach comparable values to the nearby maturity.

The pre-/ post-introduction profit comparisons do not suffice by themselves to conclude with certainty on the effect of the ETFs' introduction on futures pricing efficiency. A variety of factors have been found to explain arbitrage opportunities on futures markets among which dividends, maturity, and liquidity play a crucial role. Differences in the values of these factors and particularly in the ease to establish the index legs on the cash market between the two sample periods may explain the results. Table 5 reports descriptive statistics on the trading of CAC40 index stocks before and after the introduction of the CAC40 Master Unit ETF. The post-introduction period is associated with more trading volume, more turnover, and smaller spreads and volatility. All market conditions suggest that trading the CAC40 stock basket is easier in the second period and, whether this evolution is due to the introduction of ETFs replicating the CAC40 index or to other institutional factors, it should affect the futures market efficiency.

Table 5 about here

Therefore, we control for these different factors with the following multivariate model:

$$\begin{aligned}\left|x_{t,T}\right| = \alpha_0 + \alpha_1 CACvol_t + \alpha_2 CACspr_t + \alpha_3 CACturn_t + \alpha_4 Fvol_{t,T} \\ + \alpha_5 Fmat_{t,T} + \alpha_6 d_{t,T} + \alpha_7 ETF_t + \varepsilon_t\end{aligned} \quad (4),$$

where $\left|x_{t,T}\right|$ is the daily average of the absolute deviation, computed according to equation (2), for each class of maturity (T = 1,…,6 corresponding to futures contract with distances to maturity from 1 month to 1 year, respectively) on day t; $CACvol_t$ is the CAC40 intra-day volatility computed, for each day t, as the Parkinson (1980) volatility of the index value; $CACspr_t$ is the CAC40 average quoted spread computed as the capitalisation-weighted mean of CAC40 stocks' duration-weighted average best-limit spreads on day t; $CACturn_t$ is the daily CAC40 turnover variable and equals for each day the euro traded volume in CAC40 stocks in percentage of their total capitalisation; $Fvol_{t,T}$ is the logarithm of the daily total number of trades for futures contracts of a given maturity class T; $Fmat_{t,T}$ is the logarithm of the contract maturity in number of days at date t by maturity class T; $d_{t,T}$ is the dividend yield measured as the sum of the discounted dividends paid by the CAC40 index underlying stocks from date t to maturity in percentage of the value of the index; and ETF_t is a dummy variable that equals 0 before January 22nd, 2001 and 1 from January 22^{nd}, 2001 to July 31st, 2001. This last variable captures any eventual structural shift that could be due to the introduction of the CAC40 Master Unit, once controlled for differences in other explaining factors. Regression results are displayed in Table 6.

Table 6 about here

Concerning the effect of volatility, opposite arguments can be put forward. On the one hand, the general view is that volatility increases the probability of occurrence and the magnitude of price deviations (Yadav and Pope (1994), Kurov and Lasser (2002)). On the other hand, higher volatility may lead to a tighter spot-futures relationship by inviting more arbitrage services. Active trading correlated to volatility would accelerate price reversion and make profits vanish more rapidly. Whereas previous empirical literature has confirmed the first hypothesis, we find a significantly negative coefficient for volatility and validate the second explanation with our sample.

The payment of dividends by underlying stocks has a much clearer effect and has always been found to enhance mispricing, what we confirm with our data. Given that most French companies pay their dividends in May or June, all dividend deliveries cluster in our second period. This explain in part the larger values of deviations in spite of their lower frequency in the post-ETF period. Estimates for other index-related control variables are consistent with the intuition: ex post absolute deviations significantly increase with underlying stocks' spreads and decrease with their turnover.

The most significant variables are those related to the futures market, i.e. the daily number of futures trades and the contract maturity. The high correlation between these two factors creates collinearity. As maturity is found to have the best explanatory power (see Model 1 and Model 2 in Table 6), we drop $Fvol_{t,T}$ from the analysis and control for maturity solely. When the ETF dummy is added to that model (Model 3), its coefficient is significantly negative at the 1% threshold. This negative sign indicates a reduction in the average level of mispricing in the post-ETF-inception period which cannot be attributed to changes in volatility, liquidity or other market factors.

4.2. Ex ante deviations

We now turn to the ex ante tests of the spot-futures relationship. Every ex post deviation identified at the .145% transaction cost level is used as a signal that triggers, after a time lag of 30 seconds to three minutes, arbitrage trades, and subsequent gains or losses, designated as ex ante profits, are computed. Comparison tests are conducted for the whole population of arbitrage signals and for different categories of arbitrages: long arbitrages, short arbitrages without short sale and short arbitrages with short-selling costs. Results are presented in Table 7.

Table 7 about here

Overall, as it appears in Panel A, the introduction of the ETFs do not seem to enhance the futures market efficiency. Actually, even though pricing efficiency increases with the duration of the lag that is imposed before arbitrage execution, the persistence of profits is still high both in frequency and in value, and the introduction of the CAC40 Master Unit does not improve this pattern. For example, with a two-minute lag, 64.38% of ex post signals lead to a positive ex ante profit in post-introduction period, while this persistence frequency equalled 57.57% only in the previous period. Moreover, the average ex ante profit after the CAC40 Master Unit introduction, is three times the average profit observed before introduction.

However, this overall result hides a high variety of findings. First of all, the number of signals, or ex post deviations, drops from 13,705 before ETFs inception to only 2,176 after. Hence, there is more persistence in the post-inception period but among a smaller sample of signals. Second, buy and sell arbitrage programs differ systematically.

While no efficiency improvement is observed for long arbitrages, the frequency of positive profits and the mean value of ex ante arbitrage pay-offs decrease significantly for sell programs (cf. Panel C of Table 7). For example, for a 2-mn lag, the percentage of short arbitrages that yield gains drops from 64.32% in the pre-ETF period to 48.52% in the post-ETF period and average sell arbitrage profits become negative, falling from .02% to -.01%. The result holds for all lags, whether short-sale costs are accounted for or not.

Since initial profits are significantly different in the 2 sub-periods, the interpretation of ex ante profit levels invites further investigation. To provide a more accurate picture of the CAC40 Master Unit impact, ex ante profit values should be examined relatively to ex post profit values, the relevant question being whether the proportion of an ex post observable profit that cannot be realised due to delay in execution is larger after the ETF inception. Therefore, we conduct comparison tests on differential profits calculated as the ex ante profit minus the initial ex post profit. Results are presented in Table 8 in the same manner as for Table 7.

Table 8 about here

Overall, for all lags superior to one minute and contrary to the previous ex ante results, the loss between the average or median expected profit and the realized profit is higher once trading in ETFs has become possible. For example, at the three-minute lag for the whole sample, the difference between the average ex post profit and the average realised profit is of –.08% for the second period against –.05% for the first. Similarly to previous findings, panels B and C shows that this result is essentially assignable to sell arbitrage trades.

The impact of the introduction of the CAC40 Master Unit identified through the ex ante tests clearly differs according to the direction of the initial mispricing. The CAC40 Master Unit introduction has clearly tightened the no-arbitrage pricing relationship on its sell-arbitrage side but had no beneficial effect on its buy side. One possible explanation for this asymmetric result is an enhanced easiness to short sell in the spot market with ETF stocks, which favoured sell-arbitrage programs.

5. Time to efficiency

The present section is dedicated to the analysis of time to efficiency, that is the the time is takes for prices deviating from efficiency to revert to fair values.

5.1. Measuring time to efficiency

The measure of mispricing duration we use in this study, namely time to efficiency (TTE), has initially been proposed by Deville (2004) in efficiency tests of the French CAC40 index options markets. It is defined as the time it takes for prices to revert to values that are compatible with no arbitrage, once a deviation has been identified. The way this measure is computed is the following. For a given level of transaction costs, we identify all the spot-futures pairings that deviates from arbitrage boundaries. For these observations, we re-compute the value of equation (3), the values of the futures contract and of the index being updated every time we observe a new futures trade or a new index value. We proceed to this updating process as long as the computed “profit” remains positive. The time to efficiency is the time that goes by between the identification of the ex post deviation and the time when the profit first becomes zero or negative.

Hence, contrary to studies on the mean reversion of futures prices, we do not focus our attention on the futures price variations but also account for variations in the index value. Moreover, we do not look for a reversion in the direction of the deviation (sell arbitrages that become profitable buy arbitrages and vice versa) but for a variation in the futures price and the index value that is enough to make the arbitrage profit zero.

Time to efficiency has been computed for all spot-futures pairings deviating from no-arbitrage for the three transaction costs levels. The obtained durations as well as pre-/post-inception tests are reported in Table 9. Overall, whatever the direction of the arbitrage and the transaction costs level, index and futures prices revert to values contained between the no-arbitrage boundaries within an average of 45 minutes. For the nearby maturity, TTEs amount from an average as low as 30 seconds for the pre-inception period and the .15% transaction costs level to a maximum average of 14 minutes and 20 seconds for the post inception period and the .125% transaction costs level. Even if TTEs seem to decrease with the transaction costs level for the nearby maturity, no clear pattern appears for the other maturities.

Table 9 about here

For almost all samples but sell arbitrages at the .10% transaction costs level, TTE increases with the introduction of the CAC40 Master Unit which suggests deterioration in efficiency with significance at the 1% level. Nevertheless, this pattern must be related to be the level of the initial deviation that the market has to absorb as the level of ex post deviation is significantly higher in the post-inception period. For that reason, we seek whether the ETF effectively deteriorated the inefficiency durations after controlling for deviation value as well as other determinants, in the following regression model:

$$TTE\left(\pi_{t,T}\right) = \beta_0 + \beta_1 \pi_{t,T} + \beta_2 Fvol_{t,T} + \beta_3 d_{t,T} + \beta_4 ETF_t + \eta_t \quad (5).$$

where $\pi_{t,T}$ is the average absolute deviation, measured with a total transaction cost level of .145%, on day *t* for maturity *T*; $TTE\left(\pi_{t,T}\right)$ is the average TTE for the same date and maturity class; $Fvol_{t,T}$, $d_{t,T}$ and ETF_t are defined as in the previous section. Table 10 lays out the estimates.

Table 10 about here

Regressions of short-arbitrage TTE and long-arbitrage TTE are run separately because they exhibit different pattern. The intercept for sell-arbitrage TTE is much higher that the one for buy-arbitrage TTE, which confirms that TTE are longer in the case of short-arbitrage profit opportunities. As expected, the variable that most contributes to mispricing reduction is trading activity: TTE strongly decrease with the number of trades in the futures market for all types of deviations. The longer TTE for buy arbitrages in the second period are also explained by the higher level of profits and the delivery of dividends. Conversely to what suggested the comparison of pre- and post-ETF-inception TTE mean values, the introduction of the tracker has negatively impacted TTEs, but this positive effect on the price reversion process is significant for short-arbitrage deviations only. This result is consistent with what we found for ex ante profits.

6. Conclusion

Comparing two six-month periods, we find that the introduction of the CAC40 Master Unit securities on the French market on January 22nd 2001 has benefited efficiency and tightened the spot-futures price relationship with regard to the significant reduction in deviation frequency observed during the six months following the fund creation. When controlling for different market factors such as volatility, liquidity and dividends, average absolute deviations are found to have decreased in the post-inception period independently from these market factors. We thus validate the arbitrage and liquidity hypotheses whereas we reject the adverse selection hypothesis.

Concerning realised profits and price-reversion speed, our results are more mitigated, probably because at the time the CAC40 tracker was launched, the CAC40 index futures market was already well monitored compared to other futures markets. The fair pricing of the CAC40 futures contract was nevertheless asymmetric, sell arbitrage opportunities being more frequent than buy ones. Potential efficiency benefits, if any, were to be expected on the sell side. It is thus not surprising that our analysis of price-reversion speed, based upon a comparison of lagged-arbitrage profits and times to efficiency, leads us to the conclusion that the introduction of the CAC40 Master Unit has fastened the arbitrage process on the sell side of the cash-futures relationship solely.

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Table 1. Trading volume on CAC40 securities after CAC40 Master Unit introduction

	CAC40 stocks' cross-sectional statistics				CAC40 Master Unit	
	Mean	Median	Min	Max	Mean	Rank
Average daily traded volume (€)	91,226,184.8	59,769,501.7	12,953,632.9	406,761,649.3	33,712,242.3	29
Average daily number of trades	2,267.3	1,871.7	698.7	12,880.0	219.9	42
Average trade size (€)	36,177.8	32,499.2	12,367.7	103,532.1	153,314.1	1

This table compares trading volumes of the CAC40 Master Unit to those of CAC40 stocks from January 22nd, 2001 to July 31st, 2001, on the basis of daily traded volumes in €, daily number of trades and trade sizes in €. It provides cross-sectional statistics (mean, median, minimum and maximum) of individual CAC40-stocks' daily averages as well as the daily average for the CAC40 Master Unit and the rank of the CAC40 Master Unit when ordered against CAC40 securities.

Table 2. CAC40 futures trading activity

Futures maturity	Average daily number of trades	Average daily traded volume in number of contracts
Before ETF inception (121 trading days)		
1	10,321.7	44,454.1
2	529.2	10,465.1
3	62.9	784.4
4	35.6	1,866.7
5	11.5	151.9
6	2.3	17.5
All	10,963.0	57,739.7
After ETF inception (133 trading days)		
1	11,316.5	52,491.8
2	600.1	16,869.5
3	74.1	1,192.0
4	43.3	1,698.4
5	1.8	202.0
6	0.2	128.6
All	12,036.1	72,582.3

This table reports the average number of trades and the average number of traded contracts per day for each contract maturity over our two observation periods.

Table 3. Ex post deviations from the CAC40 spot-futures no arbitrage pricing relationship before and after CAC40 Master Unit inception

Transaction cost level	*k=0%*		*k=0,10%*		*k=0,125%*		*k=0,15%*	
Sample period	01/08/00 21/01/01	22/01/01 31/07/01	01/08/00 21/01/01	22/01/01 31/07/01	01/08/00 21/01/01	22/01/01 31/07/01	01/08/00 21/01/01	22/01/01 31/07/01
Buy arbitrages								
Violation frequency								
Number of observations	1,326,524	1,600,802	1,326,524	1,600,802	1,326,524	1,600,802	1,326,524	1,600,802
Number of violations	627,048	676,136	12,233	2,266	4,456	1,732	1,826	1,497
Percentage of violations	47.27	42.24	0.92	0.14	0.34	0.11	0.14	0.09
Z-statistic	---	-86.27	---	-88.55	---	-40.26	---	-10.97
Deviation values (in %)								
Average	0.07	0.04	0.09	0.19	0.15	0.19	0.28	0.16
Student statistic	---	-282.50	---	28.49	---	7.54	---	-14.57
Mann-Whitney statistic	---	-272.06	---	40.79	---	28.88	---	-2.66
Sell arbitrages without short sale								
Violation frequency								
Number of observations	1,326,524	1,600,802	1,326,524	1,600,802	1,326,524	1,600,802	1,326,524	1,600,802
Number of violations	698,813	923,559	35,984	4,125	20,153	2,305	9,331	1,463
Percentage of violations	52.68	57.69	2.71	0.26	1.52	0.14	0.70	0.09
Z-statistic	---	85.93	---	-167.43	---	-124.63	---	-80.12
Deviation values (in %)								
Average	0.09	0.05	0.07	0.08	0.05	0.08	0.04	0.07
Student statistic	---	-335.37	---	12.37	---	19.15	---	15.32
Mann-Whitney statistic	---	-279.28	---	6.20	---	19.18	---	15.73
Sell arbitrages with short-selling costs								
Violation frequency								
Number of observations			1,326,524	1,600,802	1,326,524	1,600,802	1,326,524	1,600,802
Number of violations			33,106	3,651	17,985	2,110	7,843	1,288
Percentage of violations			2.50	0.23	1.36	0.13	0.59	0.08
Z-statistic			---	161.29	---	117.21	---	72.73
Deviation values (in %)								
Average			0.07	0.09	0.05	0.08	0.04	0.07
Student statistic			---	15.46	---	20.48	---	17.41
Mann-Whitney statistic			---	10.57	---	20.95	---	19.80

For each sample period, that is six months prior to ETF inception (August 1st, 2000 to January 21st, 2001) and six months after (January 22nd, 2001 to July 31st, 2001), the table reports the number of observations (spot index-futures pairings), the number and percentage of violations of the no arbitrage relationship, the average mispricing in percentage of the index value, for different levels of implicit transaction costs *k* for the cash leg to which an explicit cost of .02% is added. A total trading cost of .025% is applied to the futures leg. Z-statistics test the difference in violation frequency before and after CAC40 Master Unit inception. Student statistics test the difference in average mispricing between both observation periods. Mann-Whitney statistics test the difference in median mispricing.

Table 4. Ex post deviations from the CAC40 spot-futures no arbitrage pricing relationship by maturity classes

Transaction costs level	*k=0,10%*		*k=0,125%*		*k=0,15%*	
Sample period	01/08/00 21/01/01	22/01/01 31/07/01	01/08/00 21/01/01	22/01/01 31/07/01	01/08/00 21/01/01	22/01/01 31/07/01
Panel A: Nearby maturity						
Violation frequency						
Number of observations	1,248,923	1,505,100	1,248,923	1,505,100	1,248,923	1,505,100
Number of violations	32,958	5,073	13,498	3,428	4,488	2,531
Percentage of violations	2.64	0.34	1.08	0.23	0.36	0.17
Z-statistic	---	-152.43	---	-85.00	---	-30.30
Deviation values (in %)						
Average	0.06	0.13	0.07	0.13	0.12	0.12
Student statistic	---	36.66	---	24.68	---	1.13
Median	0.04	0.10	0.03	0.10	0.03	0.09
Mann-Whitney statistic	---	46.63	---	46.79	---	26.47
Panel B: Other maturities						
Violation frequency						
Number of observations	77,601	95,702	77,601	95,702	77,601	95,702
Number of violations	12,381	844	8,943	414	5,180	254
Percentage of violations	15.95	0.88	11.52	0.43	6.68	0.27
Z-statistic	---	-111.75	---	-95.15	---	-70.34
Deviation values (in %)						
Average	0.09	0.09	0.07	0.11	0.05	0.12
Student statistic	---	-0.52	---	8.44	---	11.34
Median	0.09	0.05	0.06	0.07	0.03	0.11
Mann-Whitney statistic	---	-9.00	---	6.68	---	14.16

Table 5. Descriptive statistics on CAC40-stocks' trading activity

	Before ETF-inception **Aug. 1st,2000-Jan. 21st,2001**	**After ETF-inception** **Jan. 22nd,2001-Jul. 31st,2001**
Average daily total trading volume	3,562,453,709 €	3,694,842,986 €
Average daily total number of trades	91,595	91,197
Average turnover	0.2969%	0.3374%
Average best-limits bid-ask spread	0.1744%	0.1521%
Average CAC40-index volatility	1.0702%	1.0500%

For each observation period, this table displays the daily average of the total euro trading volume in CAC40 stocks, the corresponding average daily number of trades, the average daily turnover computed each day as the percentage of the total CAC capitalisation traded on the market, the average best-quotes bid-ask spread computed as the daily mean of the capitalisation-weighted average of duration-weighted individual stocks' bid-ask spreads and the daily mean of the CAC40-index volatility calculated with intraday values according to Parkinson (1980).

Table 6. Explaining ex post deviations from the cash-futures efficient pricing relationship

	Model 1			Model 2			Model 3		
Explaining variables	**Coefficient**	**t value**	**P-value**	**Coefficient**	**t value**	**P-value**	**Coefficient**	**t value**	**P-value**
Intercept	0.10075***	3.17	0.0016	-0.11785***	-3.63	0.0003	0.03579	0.91	0.3618
$CACvol_t$	-0.03155***	-3.66	0.0003	-0.03258***	-3.90	0.0001	-0.02406***	-2.90	0.0038
$CACspr_t$	0.81296***	4.52	<0.0001	0.62314***	3.56	0.0004	-0.13656	-0.66	0.5071
$CACturn_t$	-0.08261**	-2.17	0.0305	-0.07119*	-1.92	0.0549	-0.05488	-1.51	0.1317
$Fvol_{t,T}$	-0.01269***	-11.68	<0.0001	---	---	---	---	---	---
$Fmat_{t,T}$	---	---	---	0.04769***	14.52	<0.0001	0.04189***	12.57	<0.0001
$d_{t,T}$	0.04272***	6.57	<0.0001	0.02452***	3.68	0.0002	0.03976***	5.74	<0.0001
ETF_t	---	---	---	---	---	---	-0.05176***	-6.70	<0.0001
Number of observations	1074			1074			1074		
Adjusted R²	22.00%			26.54%			29.50%		

This table reports the estimates of OLS regressions of average absolute deviations from the efficient cash-futures price relationship, by day and by contract maturity. Deviations are calculated according to equation (2). $CACvol_t$ is the CAC40 intra-day volatility for each day *t*, computed as the Parkinson (1980) volatility of the index value. $CACspr_t$ is the capitalisation-weighted mean of CAC40 stocks' duration-weighted average best-limit spreads on day t. $CACturn_t$ equals for each day the euro traded volume in CAC40 stocks in percentage of their total capitalisation. $Fvol_{t,T}$ is the logarithm of the daily total number of trades for the *T*-maturity futures contract. $Fmat_{t,T}$ is the logarithm of the contract maturity in number of days at date t. The dividend yield $d_{t,T}$ is measured as the discounted dividends paid by the underlying stocks from date t to futures maturity in percentage of the value of the index. ETF_t equals 0 before January 22nd, 2001 and 1 from January 22nd, 2001 to July 31st, 2001. Collinearity does not allow to introduce the futures number of trades and the futures maturity in the same regression. Comparison of Model 1 and 2 shows that maturity has the highest explanatory power.

Table 7. Results of the ex ante simulated arbitrage strategies

Panel A – All arbitrages						
Delay before arbitrage	60s		120s		180s	
Sample period	01/08/00 21/01/01	22/01/01 31/07/01	01/08/00 21/01/01	22/01/01 31/07/01	01/08/00 21/01/01	22/01/01 31/07/01
Profit frequency						
Number of ex post signals	13,705	2,176	13,705	2,176	13,705	2,176
Number of positive ex ante profits	8,589	1,515	7,890	1,401	7,464	1,327
Percentage of positive ex ante profits	62.67	69.62	57.57	64.38	54.46	60.98
Z-statistic	---	6.50	---	6.14	---	5.78
Ex ante profit values (in %)						
Average ex ante profit	0.03	0.07	0.02	0.06	0.01	0.05
Student statistic	---	9.34	---	7.41		6.88
Median	0.02	0.07	0.01	0.06	0.01	0.06
Mann-Whitney statistic	---	20.84	---	18.44	---	17.18
Panel B – Buy arbitrages						
Delay before arbitrage	60s		120s		180s	
Sample period	01/08/00 21/01/01	22/01/01 31/07/01	01/08/00 21/01/01	22/01/01 31/07/01	01/08/00 21/01/01	22/01/01 31/07/01
Profit frequency						
Number of ex post signals	2,548	969	2,548	969	2,548	969
Number of positive ex ante profits	1,191	814	882	790	787	758
Percentage of positive ex ante profits	46.74	84.00	34.62	81.53	30.89	78.22
Z-statistic	---	24.24	---	30.02	---	29.38
Ex ante profit values (in %)						
Average ex ante profit	0.07	0.15	0.04	0.14	0.02	0.13
Student statistic	---	7.62	---	8.76	---	9.86
Median	-0.003	0.15	-0.03	0.14	-0.03	0.14
Mann-Whitney statistic	---	22.43	---	24.40	---	24.79
Panel C – Sell arbitrages						
Delay before arbitrage	60s		120s		180s	
Sample period	01/08/00 21/01/01	22/01/01 31/07/01	01/08/00 21/01/01	22/01/01 31/07/01	01/08/00 21/01/01	22/01/01 31/07/01
Profit frequency						
Number of ex post signals	11,157	1,207	11,157	1,207	11,157	1,207
Number of positive ex ante profits	7,398	701	7,008	611	6,677	569
Percentage of positive ex ante profits	66.31	58.08	62.81	50.62	59.85	47.14
Z-statistic	---	-5.53	---	-8.07	---	-8.41
Ex ante profit values (in %)						
Average ex ante profit	0.02	0.01	0.02	-0.01	0.01	-0.02
Student statistic	---	-1.74	---	-4.08	---	-4.91
Median	0.026	0.02	0.02	0.00	0.02	0.00
Mann-Whitney statistic	---	-0.26	---	-3.29	---	-4.45

For each sample period, the table reports statistics on the frequency and values of arbitrage profits for arbitrage strategies triggered by the observation of cash-futures mispricing (ex post signal) and executed with a delay, six different delays being considered from 30 seconds to three minutes. All arbitrage gains/losses are calculated with a .145% total transaction cost on the cash leg. Panel A provides global statistics for all categories of arbitrage strategies, either buy or sell arbitrages, with a short selling rate of .10% on the index leg for sell arbitrages. Panel B and C concern buy arbitrages and sell arbitrages with short-selling costs, respectively. Each panel displays, for a given lag, the number of futures trade times when a cash-futures mispricing is detected, the number and the percentage of profitable lagged arbitrages, the average and the median values of arbitrage gains (possible losses being taken into account) in percentage of the index value. Z-statistics test the difference in frequency of profitable lagged arbitrages before and after CAC40 Master Unit inception. Student (Mann-Whitney) statistics test the difference in the average (median) profit between both observation periods.

Table 8. Ex ante tests results based on the differences between ex ante and ex post profits

Panel A – All arbitrages						
Delay before arbitrage	60s		120s		180s	
Observation period	01/08/00 21/01/01	22/01/01 31/07/01	01/08/00 21/01/01	22/01/01 31/07/01	01/08/00 21/01/01	22/01/01 31/07/01
Number of ex post profits	13,705	2,176	13,705	2,176	13,705	2,176
Average difference	-0.03	-0.05	-0.05	-0.07	-0.05	-0.08
Student statistic	---	-5.38	---	-6.23	---	-5.94
Median difference	-0.03	-0.03	-0.03	-0.04	-0.04	-0.05
Mann-Whitney statistic	---	-2.93	---	-5.76	---	-6.54
Panel B – Buy arbitrages						
Delay before arbitrage	60s		120s		180s	
Observation period	01/08/00 21/01/01	22/01/01 31/07/01	01/08/00 21/01/01	22/01/01 31/07/01	01/08/00 21/01/01	22/01/01 31/07/01
Number of ex post profits	2,548	969	2,548	969	2,548	969
Average difference	-0.06	-0.04	-0.09	-0.05	-0.11	-0.05
Student statistic	---	4.21	---	6.56	---	7.47
Median difference	-0.04	-0.02	-0.06	-0.02	-0.07	-0.03
Mann-Whitney statistic	---	9.55	---	11.64	---	11.35
Panel C – Sell arbitrages						
Delay before arbitrage	60s		120s		180s	
Observation period	01/08/00 21/01/01	22/01/01 31/07/01	01/08/00 21/01/01	22/01/01 31/07/01	01/08/00 21/01/01	22/01/01 31/07/01
Number of ex post profits	11,157	1,207	11,157	1,207	11,157	1,207
Average difference	-0.03	-0.07	-0.03	-0.09	-0.04	-0.10
Student statistic	---	-7.90	---	-9.47	---	-9.84
Median difference	-0.02	-0.04	-0.03	-0.05	-0.03	-0.06
Mann-Whitney statistic	---	-10.02	---	-13.58	---	-14.07

For each sample period, the table reports statistics on the difference between profits resulting from an arbitrage triggered by the observation of a cash-futures mispricing and the ex post profit that served as a signal. Six different delays between the signal and the execution of the arbitrage from 30 seconds to three minutes are considered. All arbitrage gains/losses are calculated with a .145% total transaction cost on the cash leg. Panel A provides global statistics for all categories of arbitrage strategies, either long-hedge or short-hedge with a short selling rate of .10% on the index leg for short-hedge arbitrages. Panel B and C concern buy arbitrage strategies and sell arbitrage strategies with short-selling costs, respectively. Each panel displays, for a given lag, the number of mispricing signals, the average and the median values of the ex ante profit minus the observed ex post profit in percentage of the index value. Student (Mann-Whitney) statistics test the difference in the average (median) differential profit before and after CAC40 Master Unit inception.

Table 9. Time to efficiency of the CAC40 index futures for pre-(01/08/00-22/01/01) and post-CAC40 Master Unit inception (22/01/01-31/07/01) samples

Transaction cost level	*k=0,10%*		*k=0,125%*		*k=0,15%*	
Observation period	Pre-	Post-	Pre-	Post-	Pre-	Post-
Panel A. Buy arbitrages						
Average TTE (in seconds)						
Nearby maturity	109	690	86	860	144	495
Student statistic	---	38.85	---	46.35	---	32.07
Other maturities	627	937	878	1206	1094	1349
Student statistic	---	1.90	---	1.47	---	0.93
Panel B. Sell arbitrages with short-selling costs						
Average TTE (in seconds)						
Nearby maturity	258	415	80	250	30	137
Student statistic		13.10		24.54		18.63
Other maturities	2444	1001	1107	1543	488	2532
Student statistic	---	-10.28	---	1.66	---	4.58

Table 10. Explaining time to efficiency

Dependent variables	$TTE\left(\pi_{t,T}^{buy}\right)$			$TTE\left(\pi_{t,T}^{sell}\right)$		
Explaining variables	**Coefficient**	**t-statistic**	**P-value**	**Coefficient**	**t-statistic**	**P-value**
Intercept	7.95923***	11.94	<0.0001	9.22959***	27.65	<0.0001
$\pi_{t,T}$	3.07289***	3.46	0.0008	0.23786	0.28	0.7822
$Fvol_{t,T}$	-0.65014***	-8.56	<0.0001	-0.67901***	-13.22	<0.0001
$d_{t,T}$	1.20229**	2.05	0.0436	0.05285	0.19	0.8495
ETF_t	-0.46429	-1.34	0.1822	-1.17893***	-4.03	<0.0001
Number of observations	98			191		
Adjusted R²	61.16%			58.58%		

$TTE\left(\pi_{t,T}^{buy}\right)$ and $TTE\left(\pi_{t,T}^{sell}\right)$ are the daily averages of times to efficiency in logarithm, respectively for long and short arbitrage profits, measured on day *t* for contracts of maturity *T*. $\pi_{t,T}$ is the mean profit, either for long arbitrages or for short arbitrages, on day *t* for maturity *T*. All profits are computed assuming a total transaction cost of .025% for the futures leg and .145% for the index leg. For short arbitrages, a short selling rate of .10% is applied on the cash leg. $Fvol_{t,T}$ is the total number of trades in logarithm for the maturity class *T* on date t. $d_{t,T}$ is the total amount of discounted dividends paid by the index from date t to maturity in percentage of the index value. ETF_t is a dummy variable equal to 0 (1) before (after) ETF inception.