CHEUVREUX
CRÉDIT AGRICOLE GROUP

QUANT **NOTE**

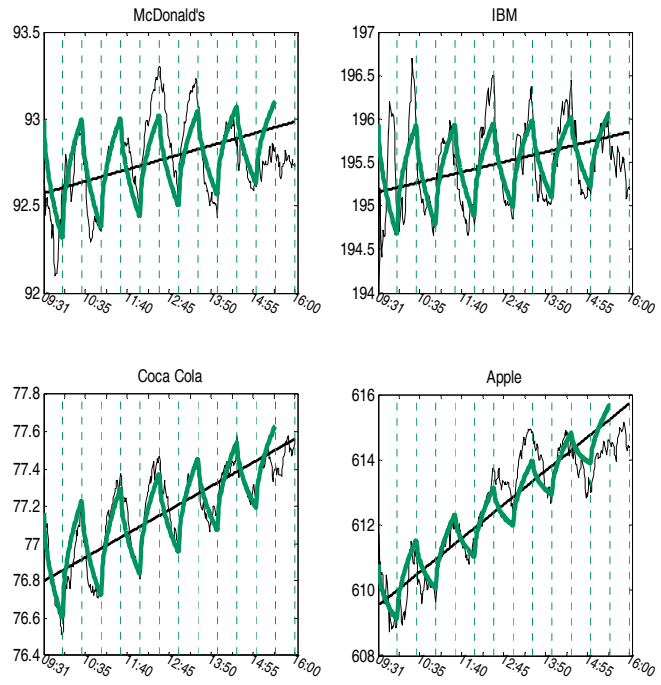
28th of August, 2012

What does the saw-tooth pattern on US markets on 19 July 2012 tell us about the price formation process

The saw-tooth patterns observed on four US securities on 19 July provide us with an opportunity to comment on common beliefs regarding the market impact of large trades; its usual smoothness and amplitude, the subsequent "reversal" phase, and the generic nature of market impact models.
This underscores the importance of taking into account the motivation behind a large trade in order to optimise it properly, as we already emphasised in *Navigating Liquidity 6*.

We used different intraday analytics to work out what happened: pattern-matching techniques, market impact models, order flow imbalances and PnL computations of potential stat. arb intraday strategies. After looking at open interests of derivatives on these stocks, we conclude that repetitive automated hedging of large-exposure derivatives lay behind this behaviour. This is an opportunity to understand how a very crude trading algorithm can impact the price formation process ten times more than is usually the case.

FIGURE 1: SAWTOOTH PATTERNS ON COCA-COLA, MCDONALD'S, IBM AND APPLE ON 19 JULY 2012



The market impact is one of the main factors of the price formation process

Strange patterns were observed on four large cap US stocks (Coca-Cola, McDonald's, IBM and Apple) on 19 July 2012. A few days later the "Knight Algorithm Went Crazy" issue eclipsed this strange phenomenon, by raising the usual concerns about the current market microstructure, the integrity of the price formation process, etc.

We have been hearing such complaints for years now (during the public hearing in MiFID Review in September 2010, after the SEC issued a concept release seeking comment on the structure of equity markets in January 2010). What has changed? Not much: we continue to observe glitches on US markets, and the MiFID review in Europe has been under discussion for months, with no clear agenda about elements as crucial as the tick size.

We look at the events of 19 July to learn more about the price formation process. Our intention here is not to merely say that the way a (reputed) fair price is formed, thanks to matching of supply and demand, is simple. The roots of its mechanism are not very difficult to understand. Its complexity stems from the way they combine.

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I— Seven saw-tooth to test the Price Formation Process mechanisms

The key elements of the price formation process illustrated by these strange patterns are:

- Usual daily volume variations are large. Nevertheless, a uniform increase in trading volume every minute of the trading day is an aberration.
- It is commonly believed that the market impact follows a regular and smooth curve. This is not the case; the curves we all have in mind (see *Navigating Liquidity 6*) come from averages on a huge number of executions; regular curves such as those of 19 July is an aberration. The amplitude itself had nothing to do with that created by the "usual" market impact.
- After the market impact comes a reversal. "Reversal" means a relaxation of price dynamics, with the return to a previous price level (i.e., before the market impact took place). The remaining price change is a "permanent" market impact. In the real world, a smooth reversal can be seen only on averaged executions, and the way the market relaxes is very slow; a rule of thumb would be to consider that it takes more trading volume to end a reversal than to impact the price beforehand. **The saw-tooth pattern on 19 July is clearly not one in which impact and reversal phases alternate**.
- The "Market Impact Model" is pursued as the Holy Grail of optimal trading. Unlike Lancelot, who understands too late that he will only find his own holiness in the Grail, Galahad's knowledge should be largely shared: **market impact is a function of the trading tactic that is used**. The subtler the tactic, the less the market impact. The trading tactic used on 19 July was so heavy-handed that it impacted the price dozens of times over compared to a traditional trading algorithm.

Last, but not least, the following assumption about the PFP has to be reconsidered in light of this event, namely the maturity of market participants in terms of understanding orderbook dynamics. It is plausible that these moves were originated by a derivative hedging strategy that did not take into account the slightest element of common knowledge of market microstructure.

II—What was observed on Coca-Cola, McDonald's, IBM and Apple on 19 July 2012

Saw-tooth patterns explained most of the moves of these stocks

The share prices of Coca-Cola, McDonald's, IBM and Apple on 19 July 2012 showed strikingly **regular and synchronised patterns**. Starting at 10.00 a.m., prices increased for exactly 30 minutes and then decreased for the next 30 minutes, and so forth, producing a saw-tooth-like pattern throughout the trading day. The phenomenon only disappeared in the last hour of trading.

On FIGURE 1, the green solid curve represents the pattern component of the prices. The vertical dotted lines show the 30-minute intervals, and we can clearly see that the local highs and lows happened exactly at these half-hour marks. Moreover, the decreasing and increasing phases are symmetrical: the ascending phase being concave and the descending phase being convex.
One last thing we note is that the pattern becomes slightly attenuated: its amplitude decreases by about 25% between the first and the last oscillation.

Pattern trace on the Dow Jones

Now that we have isolated the pattern, we can try to see if there are traces of it in other stocks, more precisely we looked into all the components of the Dow Jones.

To do that, for each stock, we compare the quality of a model fitted with a trend and the pattern, to a model using the trend only. The higher the difference the more the pattern is present in the stock. Then we asserted the significativity of the pattern trace in each stock by designing a test (using Monte Carlo Simulations) which provides us the following *trace probability*. A value of 100% means we are certain that the pattern is present, whereas a value lower than 95% means that the pattern trace isn't statistically present in the stock.

TABLE 1: PATTERN TRACE SIGNIFICATIVITY

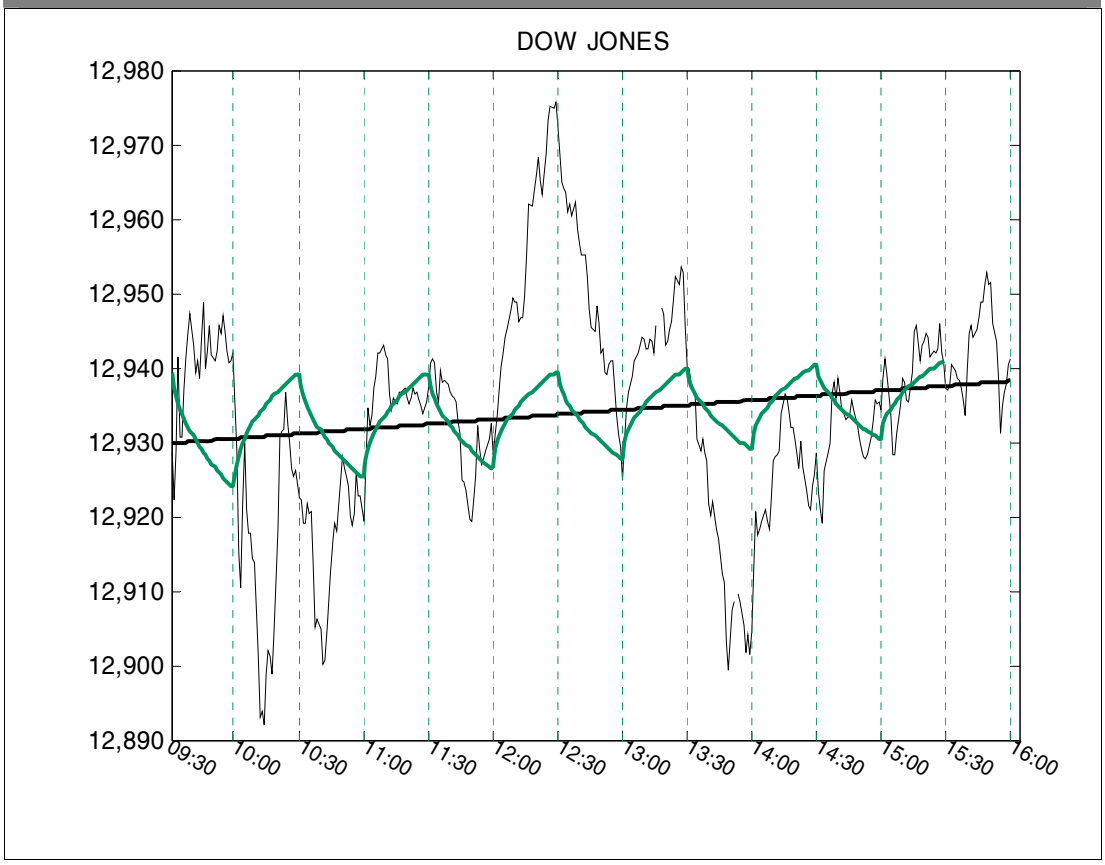
Symbol	Trace probability (%)
KO	100%
IBM	100%
AAPL	100%
MCD	100%
HPQ	98%
WMT	88%
MRK	73%

Source: Crédit Agricole Cheuvreux Quantitative Research

Table 1 list the stocks where the pattern trace is most present. It is significantly present in our four stocks of interest as well as HPQ (Hewlett-Packard).

However the pattern in Hewlett-Packard is obviously not as clear as the one for the four stocks in question, the trace comes from the fact that ascending and descending phases correspond to those of the pattern (with an almost perfect match on the phase between 1:00 pm and 2:00 pm).

FIGURE 2: PATTERN ON THE DOW JONES



Source: Crédit Agricole Cheuvreux Quantitative Research

Even if the pattern is not readable on the Dow Jones, Figure 2 printing the corresponding saw-tooth on it shows that oscillations of the whole index are not totally independent of this phenomenon. The trace in the index can be explained by the fact that IBM (weight: 11.4%), Coca-Cola (weight: 4.5%) and McDonald's (weight: 5.4%) are components of the Dow Jones. All together their weight represents one-fifth of the total index. (Note that these figures represent Coca Cola's price as of 19 July, before its August split).

If an index is usually taken as a proxy for "the market" to understand the price moves of stocks, in the case of the intraday PFP (Price Formation Process), the index moves are often a "by product" of the isolated PFPs.

Drilling down to the components of the Price Formation Process

The phenomenon that happened on 19 July 2012 on Coca-Cola, McDonald's, IBM and Apple was also observable in traded volumes, in the orderbook dynamics and in the way the PFP (Price Formation Process) itself was formed.

Volumes show a uniform surplus compared to the other days

The traded volumes on the four stocks of interest were not significantly higher or different from what was usually traded each day in July. Nevertheless, if we take a look at intraday volumes on 19 July, we note that there something different is happening. FIGURE 3 shows five-minute volumes, in number of shares, on Coca-Cola for each day of the week 16-20 July 2012. We represented 19 July volumes in black dots. These volumes are clearly upward-shifted compared to other days. FIGURE 4 shows the distribution of the logarithm of one-minute volumes divided by the total volume for the day, on Coca-Cola, for each day from 16 July to 20 July 2012. The black curve, which represents 19 July, is shifted compared to other days.

FIGURE 3: INTRADAY 5-MINUTE VOLUMES ON COCA-COLA, FOR THE WEEK 16 TO 20 JULY 2012

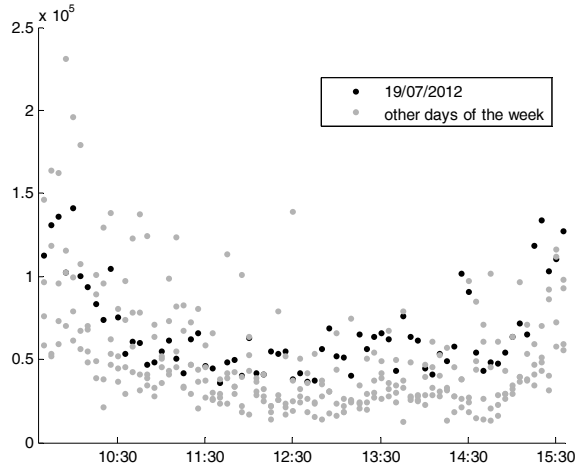
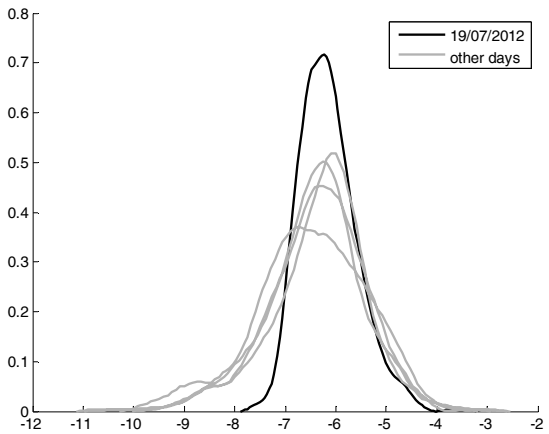


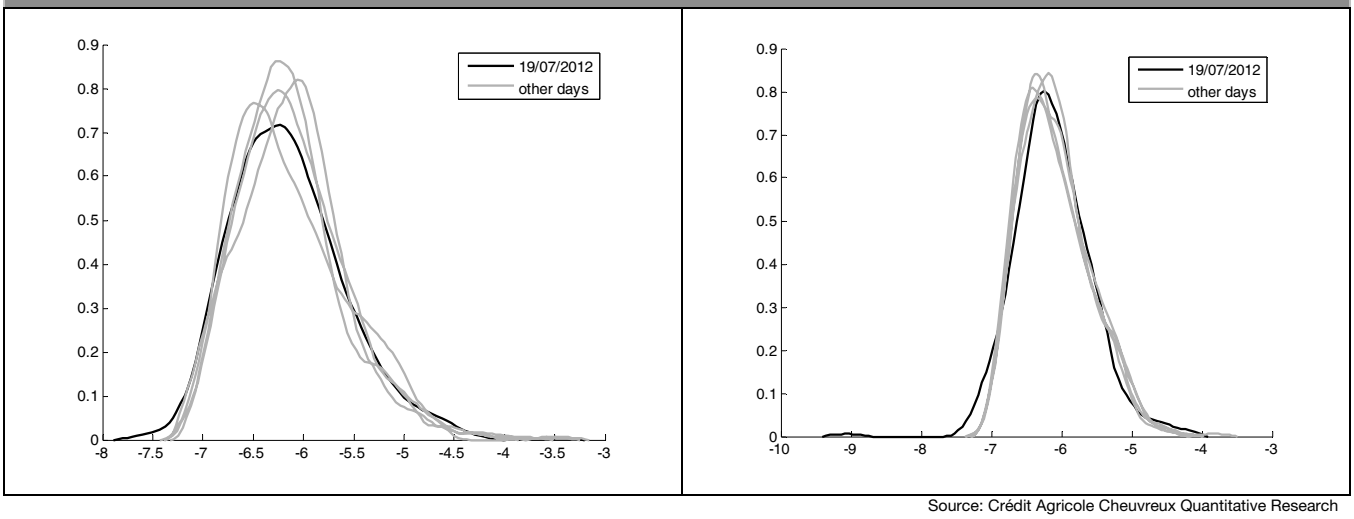
FIGURE 4: DISTRIBUTION OF LOG 1-MINUTE VOLUMES DIVIDED BY VOLUME OF THE DAY ON COCA-COLA



Source: Crédit Agricole Cheuvreux Quantitative Research

FIGURE 5 present the same distribution as above on Coca-Cola and Apple, but the distributions of the other days have been adjusted. The adjustment adopted is the following: for each day we add a surplus uniformly to all one-minute volumes. This surplus is equal to a percentage of the total volume of the day, divided by the number of one-minute intervals in a trading day. We chose the percentage so that the adjusted distributions look like those of 19 July. In the case of Coca-Cola and Apple the extra volumes are respectively 27% and 33% of each daily volume.

FIGURE 5: DISTRIBUTION OF LOG-ADJUSTED 1-MINUTE VOLUMES DIVIDED BY VOLUME OF THE DAY (COCA-COLA AND APPLE)



Source: Crédit Agricole Cheuvreux Quantitative Research

Two remarks:

- On 19 July, there was algorithm trading on the four stocks that sent orders to the market at a relatively fast rate. Fast enough at least **to be the counterpart of a trade almost every minute**.
- Shifted one-minute volumes of the other days enable one to find distributions that are virtually the same as those of 19 July. This extra volume is deemed to be 30% of daily volume for each of the four stocks. **We can thus infer that the participation rate of the market player responsible for the saw-tooth pattern was at least 30%**.

The saw-tooth pattern looks like a market impact curve

There is evidence related to market impact and reversal profiles that proves that a **trading algorithm is pushing prices up and down, rather than there being market impact followed by a relaxation**.

FIGURE 6 shows the log-prices in number of bid-ask spreads of McDonald's on 19 July 2012 from 10:00 to 15:00 rebased each round hour at 0. We superposed a market impact curve, again in number of bid-ask spreads, (solid black curve) built using one year of Cheuvreux execution data. What strikes us most when looking at FIGURE 6 is that we can see the impact. Usually market impact is almost invisible. We thus plotted on FIGURE 6 the market impact curve of a hypothetical 30% POV that would be trading during 30 minutes (dotted curve). Its impact is negligible compared to the pattern.

TABLE 2: IMPLICIT PARTICIPATION

Symbol	Implicit participation ratio (%)
KO	988
MCD	735
IBM	714
AAPL	598

Source: Crédit Agricole Cheuvreux Quantitative Research

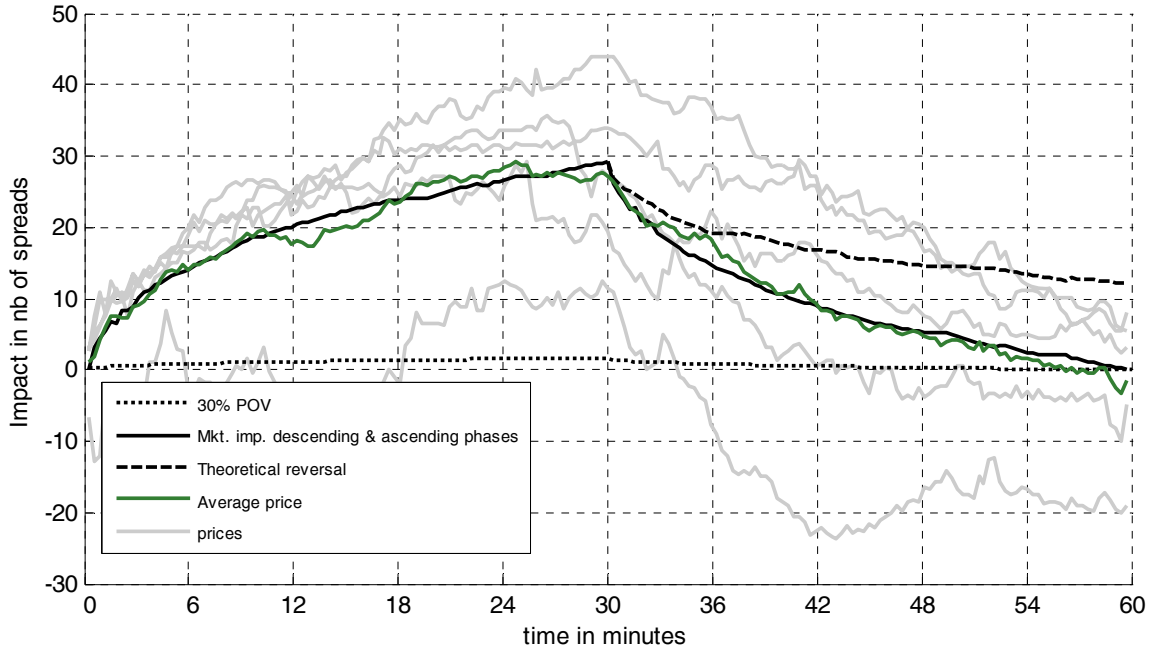
Table 2 presents the implicit participation rate obtained to build our market impact model on the ascending phase of the pattern. **The implicit participation rate is the rate one needs to input to get the same impact as the one we see on the pattern over a 30-minute period**. For instance, for McDonald's, in order to get a 27 bid-ask spread impact over 30 minutes we would have to execute seven times the usual volume of the market over that period.

These aberrant rates underlines the fact that there is not one generic market impact associate to a surplus of volume: each trading tactic has its own market impact. The less subtle, the more information leakage via orderbook dynamics and the more the impact.
This shows that the **trading algorithm responsible** for the 19 July surplus was **very mechanic and predictable, moving the whole orderbook and not just taking liquidity**.

Someone is impacting the market during both phases

We plotted the average of the rebased prices as the solid green curve on FIGURE 6. The impact curve (the black solid curve) has been set, as described previously, so that it optimally matches this average. We also plotted the theoretical price reversal curve (the dashed curve). Price reversal is when the price reverts after the end of an execution to its level on arrival. We would like to test whether the descending phase is price reversal or not. In FIGURE 6, we see that over the half-hour descending phase (the second half of the chart, i.e., from 30 to 60 minutes) prices do revert, but faster and lower than during a pure price reversal. This is the **sign that an algorithm is impacting the market during both the ascending and descending phases**. As confirmation of this, we see that the average of the rebased prices sticks to the market impact curve in either the ascending or descending phases.

FIGURE 6: MCDONALD'S ASCENDING & DESCENDING PHASES, 19 JULY 2012



Source: Crédit Agricole Cheuvreux Quantitative Research

According to our model, the implicit participation on the four names on 19 July should be several multiples of the usual daily volume. This is clearly not what happened! The **volumes on 19 July were not excessive** compared to volumes on other days. We also believe that the participation rate of the agent responsible for what happened that day was 30%. Given that the price was thus impacted, it is either because the market participant responsible for the **saw-tooth pattern suffered from massive information leakage** or (the result being the same) the participant's trading style was very aggressive.

Flow imbalance analysis shows more than market impact and relaxation only

As we have stated in previous sections, the price moves of Coca-Cola, McDonald's, IBM and Apple on 19 July 2012 cannot be explained in terms of market impact only. There is something else happening that is related to the trading styles of the market participants on this particular day. We thus need to delve deeper into the dynamic of the price formation process.

The first idea that comes to mind is that there is unusual, extended and strong pressure put on the price alternately (every 30 minutes) by buyers and sellers.

Order Imbalance (OI) evidences: liquidity takers followed a saw-tooth pattern

A common way to measure buy or sell pressure using tick-by-tick data is to look at the imbalance between buyer-initiated and seller-initiated trades. This measure indicates which impatient (or aggressive) agents are more represented in the market.

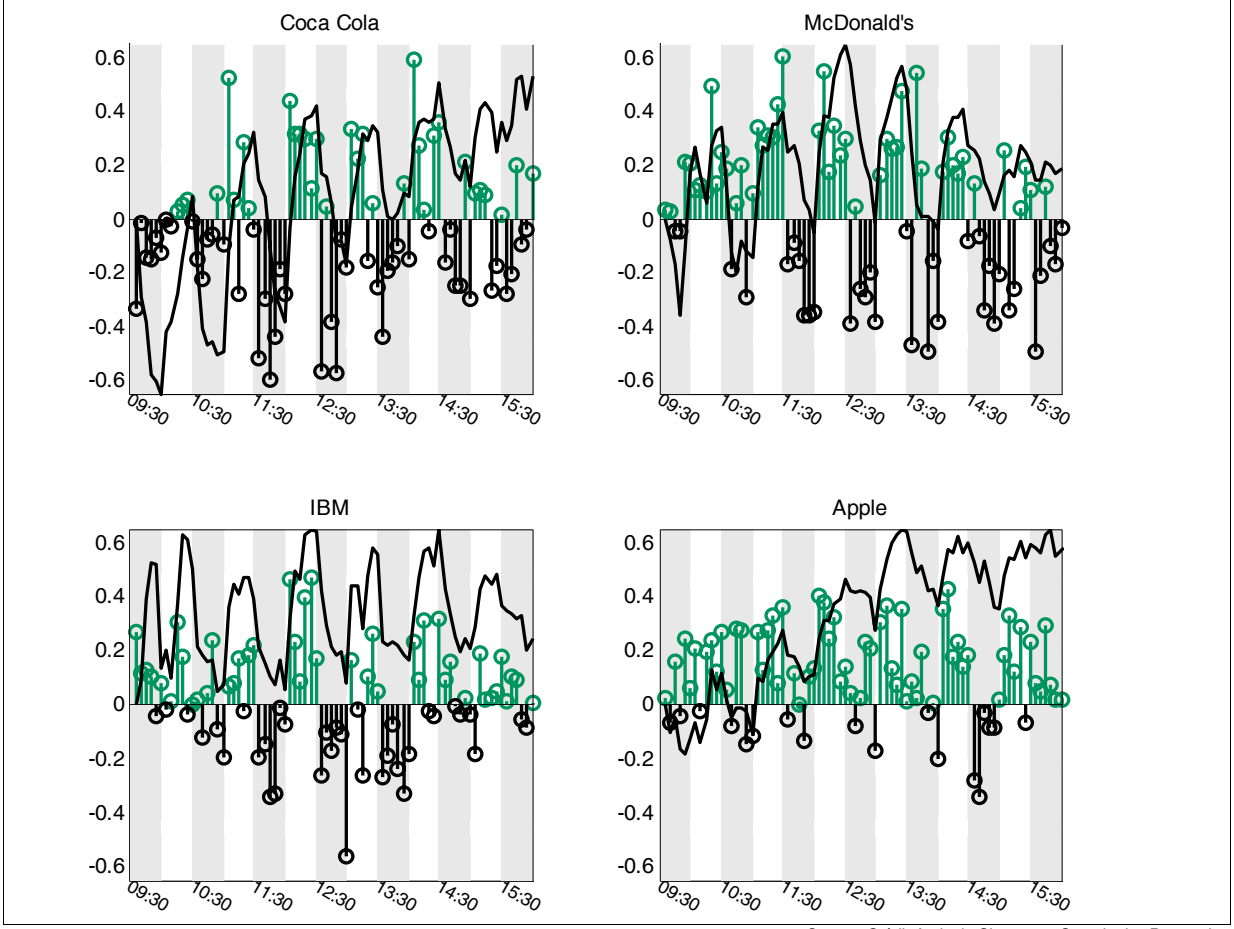
In the following formula, a trade is considered buy-initiated if the price is above the mid price of the NBBO (national best bid and offer), and sell-initiated if under. Aggregated over a selected period of time, order imbalance is computed as:

$$OI = \frac{volume(buy\ initiated) - volume(sell\ initiated)}{volume(buy\ initiated) + volume(sell\ initiated)}$$

OI is an indicator that varies between -1 and 1. For instance, a value greater than 0 indicates that aggressive-buyers are over-represented, meaning that agents that want to buy the stock are more impatient than ones that want to sell the stock. This indicates that pressure from buyers makes the price move up.

FIGURE 7 compares the OI aggregated (sum) on 5-minute bins (vertical bars) to the price moves on 19 July of the four stocks of interest.

FIGURE 7: PRICE MOVE + ORDER IMBALANCE, 19 JULY 2012



Source: Crédit Agricole Cheuvreux Quantitative Research

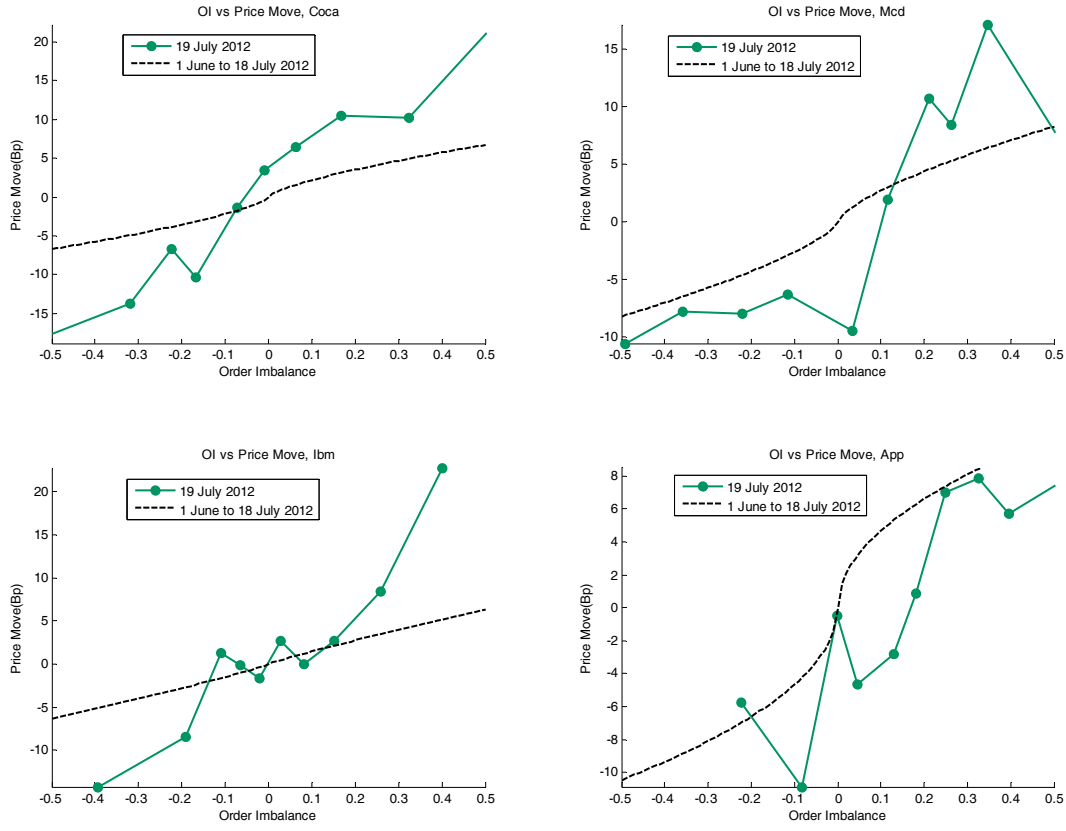
For Coca-Cola, McDonald's and IBM, almost every upward period of 30 minutes (resp. downward) shows an order imbalance greater than 0.1 (resp. lower than -0.1) meaning that aggressive buyers (resp. sellers) are over-represented during each 5-minute subsample period. This relationship is still visible when going deeper in frequency till 1-minute subsample periods.

On the other hand, for Apple, the order imbalance tends to be positive even during the downward period of 30 minutes. This means that aggressive buyers tend to be over-represented throughout the day and at each smaller frequency (5-minutes for instance).

We can thus **conclude that the pressure from aggressive agents on market prices** (of Coca-Cola, McDonald's and IBM) **is very strong and steady in time during each 30-minute period**. The way the price will move can then be deduced easily! However for Apple, the pattern is not the same, indicating that the agents creating the saw-tooth price move are potentially not the same, or are just less represented.

We now look at FIGURE 8 below, which compares the relationship between OI and the price move (in bps) for 19 July, in green, and the usual one, in black (data from 1 June 2012 to 18 July 2012).

FIGURE 8: PRICE MOVES VS. ORDER IMBALANCE



Source: Crédit Agricole Cheuvreux Quantitative Research

In FIGURE 8, we note:

- As seems obvious, order imbalance and price moves are positively correlated, meaning that the price move is usually driven by the more impatient agents.
- Aggressive buyers/sellers moved prices more easily (except for Apple) on 19 July than during a usual day. This observation suggests relatively weaker resistance of the liquidity provider and therefore that they had more information than usual.

Indeed, in order to fully understand the determinant of a price move, it is not enough to merely look at the behaviour of the aggressive agents; the latter has to be linked with that of passive players (or liquidity providers). Passive players also put pressure on prices and induce the behaviour of aggressive agents (and vice-versa).

OBI (Order Book Imbalance) behaviour: liquidity providers followed a saw-tooth pattern too

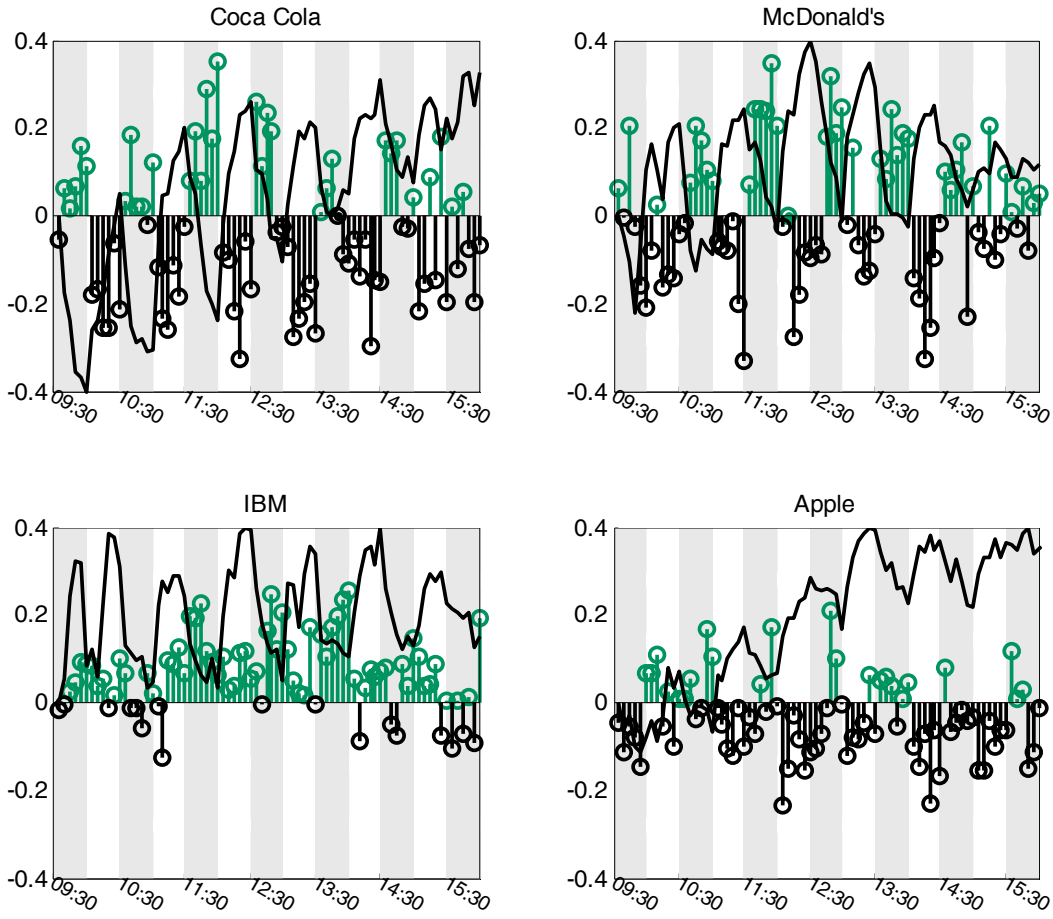
Another way to measure buy and sell pressure is to look at the imbalance between available quantities at the best bid and best ask price. This measure of buy/sell pressure indicates which patient (or passive) agents are more represented in the market.

The order book imbalance (OBI) is defined by:

$$OBI = \frac{bid\ size - ask\ size}{bid\ size + ask\ size}$$

OBI also varies between -1 and 1. For instance, a value greater than 0 means that the quantity shown by the highest buyers is bigger than that of the lowest sellers. This indicates that the pressure of passive buyers makes the price move up.
FIGURE 9 compares the OBI aggregated (average value over the period) on 5-minute bins (vertical bars) to the price moves on 19 July of the four stocks of interest.

FIGURE 9: PRICE MOVE + ORDER BOOK IMBALANCE ON 19 JULY 2012



Source: Crédit Agricole Cheuvreux Quantitative Research

For Coca-Cola and McDonald's, all the 5-minute OBI are negative during the up-phase and positive during the down-phase, meaning that passive sellers (at best price) are over-represented during the up-phase and passive buyers (at best price) are over-represented during the down-phase. On the other hand, there is no obvious relationship between OBI and price moves for IBM and Apple.

The strong relationship noted for the first two stocks is relatively counterintuitive with the concept we thought we had established for pressure from passive players. Indeed, OBI is usually correlated positively to the price move.

This last phenomenon tends to happen under specific market conditions: assuming an up-movement, lots of aggressive orders consume the whole first limit and thus reveal, more often, the second best limit, where more quantities are often available.

Following that, some passive sellers subsequently cancel their orders at the best limit and replace these quantities at the further limits. In the meantime, passive buyers increased their best price.

Actually, these passive buyers could be the same traders as the aggressive ones using the following trading tactic: they buy the entire first quantity posted on the best offer and post an order at this limit. This kind of tactic is very aggressive and will result in an immediate response from the orderbook, producing high impact.

This assumption is completely in line with our other facts. Indeed, it explains why:

- the price can move up and down without significantly unusual trading volume; and
- aggressive market participants moved the price more easily on 19 July than during a usual trading day.

Finally, the above analysis highlights the fact that **market participants responsible for the saw-tooth pattern were suffering from information leakage**. A further deal/book analysis will reveal the very essence of the phenomenon.

Phenomenon analysis through the Deal/Book price split

Breaking down the price move into "Deal" and "Book" components underpins the scenario of information leakage.

The three features are as follows:

- The volumes study showed that a 30% participation trading algorithm is likely to be present most of the day on the four stocks in question.
- The saw-tooth pattern impact study showed the presence of a direct impact in both upward and downward price movements as suggested by impact considerations.
- The flows imbalance study reveals that pressure put by aggressive agents move the price in up- and down-phases. The first limit orders study shows that books retreat due to these aggressive participants during each trading phase.

The Deal/Book split is very useful with regard to getting an integrated vision of both deal and book behaviours in a dynamic way. **The remaining question is what drove the prices. Deals or Books? Which part of the price movement can be explained by each component?** Only then can the puzzle be solved, and the right split between deal aggressiveness/passiveness and book resilience/retreat be found.

Our method for deciphering intraday price moves

Any price change is the matching of two elements: a market order and an order in the book. It is commonly believed that these two components are so intrinsically linked that they cannot be disentangled. Up to now, no methods have existed to break down the price changes according to these two components.

Based on tick-by-tick data, our new method provides such a breakdown for any single security or any basket and over any period of time (from an intraday to a yearly scope):

Price change = Deal component (difference in expected prices due to a deal)

\+

Book Component (difference in expected prices between two deals)

The expected price is calculated according to a proprietary objective probability measure.

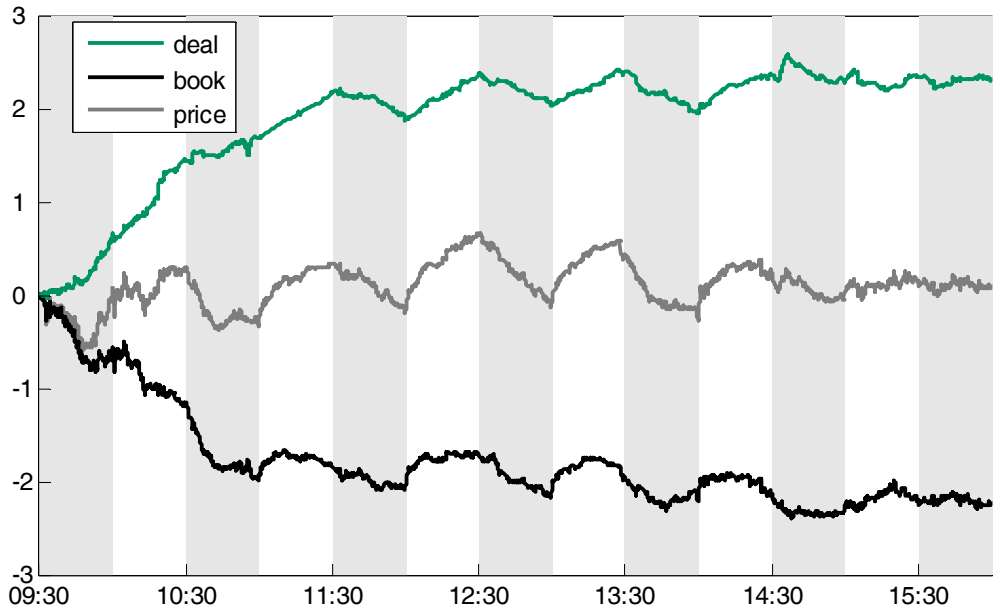
Deal /Book split applied to McDonald's

The breakdown of McDonald's price in FIGURE 10 shows a very interesting similarity: the "deal component" (green), and the "book component" (black) of prices both showed the same saw-tooth pattern.

Deals contributed through their aggressive behaviour to price rises and falls during each trading phase. This fact confirms the above market impact analysis. In addition to a classic "imbalance analysis", examination of the "deal component" reveals that the deals contribute just as equally to price appreciation as books do.

The book component behaves in a unique way. Usually books resist aggressive orders at the origin of the trend. Here the "book component" reverts as soon as the deals revert. This rare pattern **underpins the scenario of "information leakage"**, which would explain why this market doesn't show any resilience and retreats so rapidly faced with aggressive deals.

FIGURE 10: DEAL/BOOK BREAKDOWN OF MCDONALD'S, DAILY PRICE CHANGE (%)



Source: Crédit Agricole Cheuvreux Quantitative Research

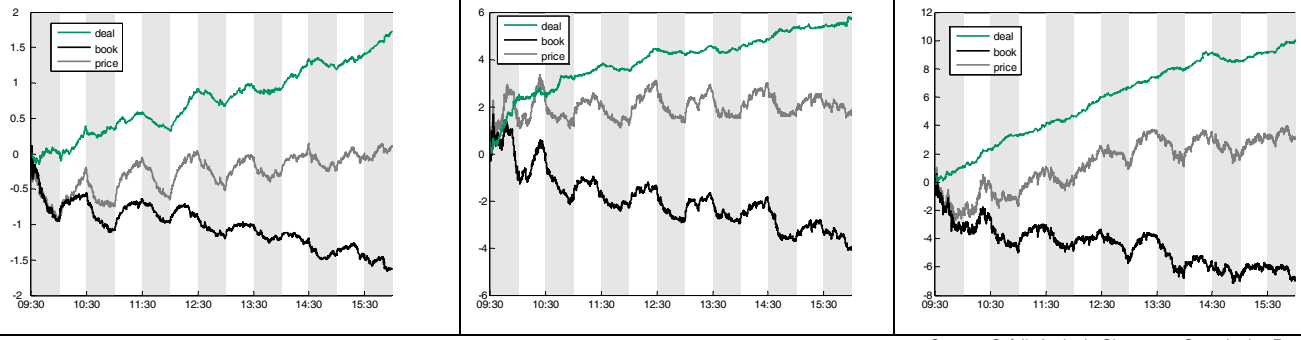
Analysis of all four stocks in question

The same features apply to all four stocks:

- **No Book resilience, rapid book retreat**
- **Price moves driven by both Deals and Books**

The Deals component features are less contrasted for IBM and Apple (FIGURE 11) but the Book component aspects are very similar across all four stocks.
This supports of our scenario of aggressive orders and information leakage that deter any book resilience, and therefore allow amplified market impacts to occur during each 30-minute trading phase.

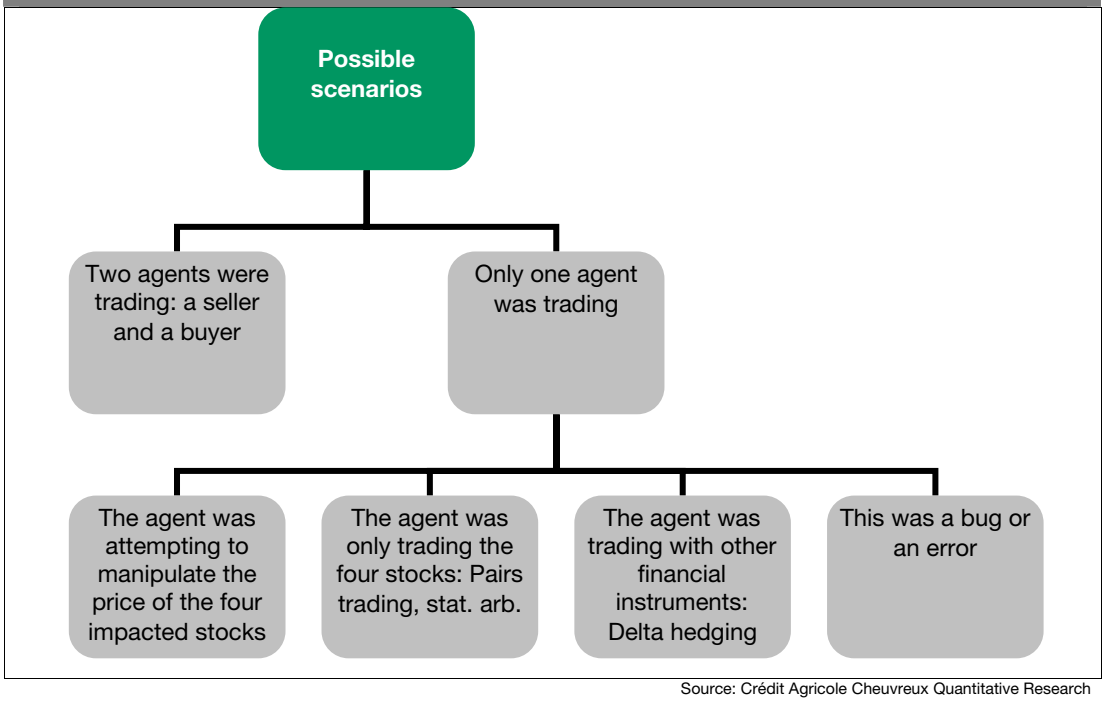
FIGURE 11: DEAL/BOOK BREAKDOWN OF COCA-COLA,IBM AND APPLE, DAILY PRICE CHANGE (%)



Source: Crédit Agricole Cheuvreux Quantitative Research

III— Possible behaviour explaining the patterns

FIGURE 12: POSSIBLE SCENARIOS ON 19 JULY 2012



Source: Crédit Agricole Cheuvreux Quantitative Research

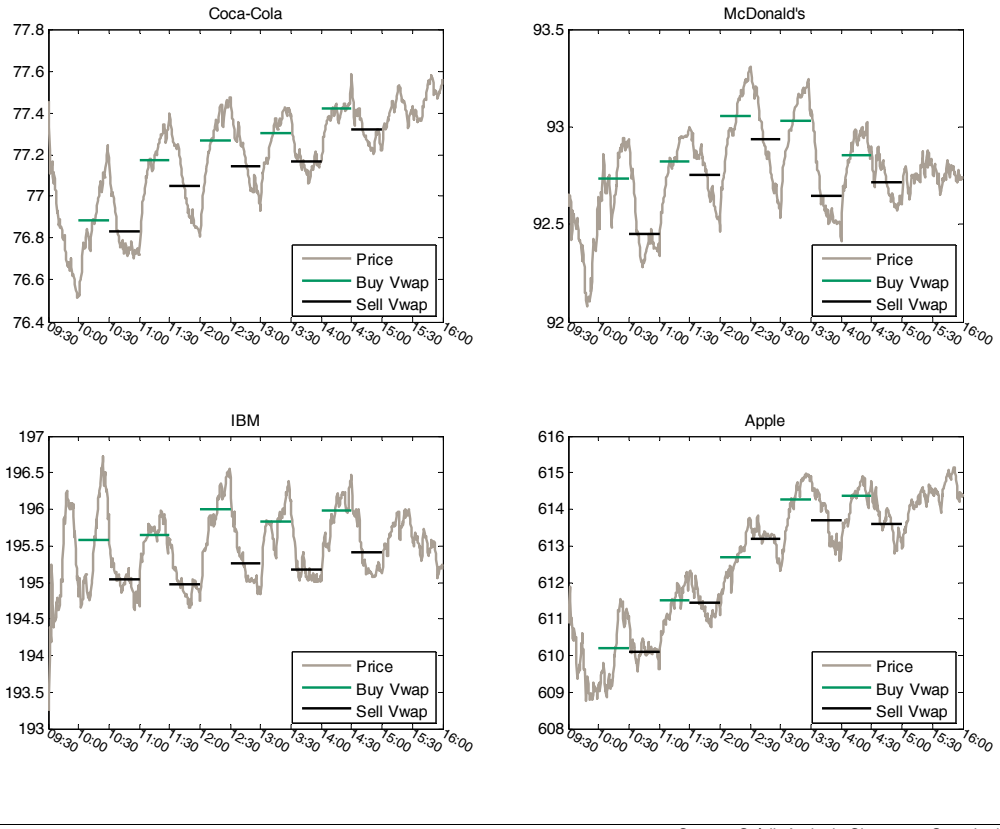
As mentioned above, the prices of Coca-Cola, McDonald's, IBM and Apple on 19 July 2012 showed a saw-tooth pattern because a market participant was moving prices up and down. Several market participants could be responsible for this: the first ones moving prices up and others moving them down. This hypothesis is valid as long as the sellers and the buyers are perfectly coordinated. Such a high degree of coordination, as is backed up by the regular nature of the pattern, seems unrealistic, from our perspective. Moreover, we do not believe in a "bug" because, as shown by the "Knight Algorithm Went Crazy" issue, a bug usually does not exhibit regular behaviour, and having a "bug" repeated hourly for a few hours seems unrealistic. **We thus believe that there was only one agent alternately selling and buying these four stocks**.

Various possible scenarios could explain the saw-tooth pattern (see FIGURE 12:). We will study each one of these scenarios in this section of the document. Is this market participant deliberately trading to make money out of the pattern? In other words, **is it a price manipulation strategy?** If not, **is it the result of a statistical arbitrage strategy such as pairs trading?** Finally, it could also be a **delta hedging process** that is the source of these oscillations.

One agent selling and buying each stock to make money: (a strategy that does not include any other stocks)

When we look at the pattern for Coca-Cola, we note that the troughs are ascending. We might thus think that, by buying the stock in the upward period and selling it in downward period, money could be made, as the price increase in the former period is larger than the price decrease in the latter. However, as we show in the following figure, generally (in fact every time but once) the VWAP (volume weighted average price) for the first period is higher than the VWAP for the second, thus executing a VWAP algorithm in every period is a losing strategy.

FIGURE 13: VWAP OF DIFFERENT PERIODS



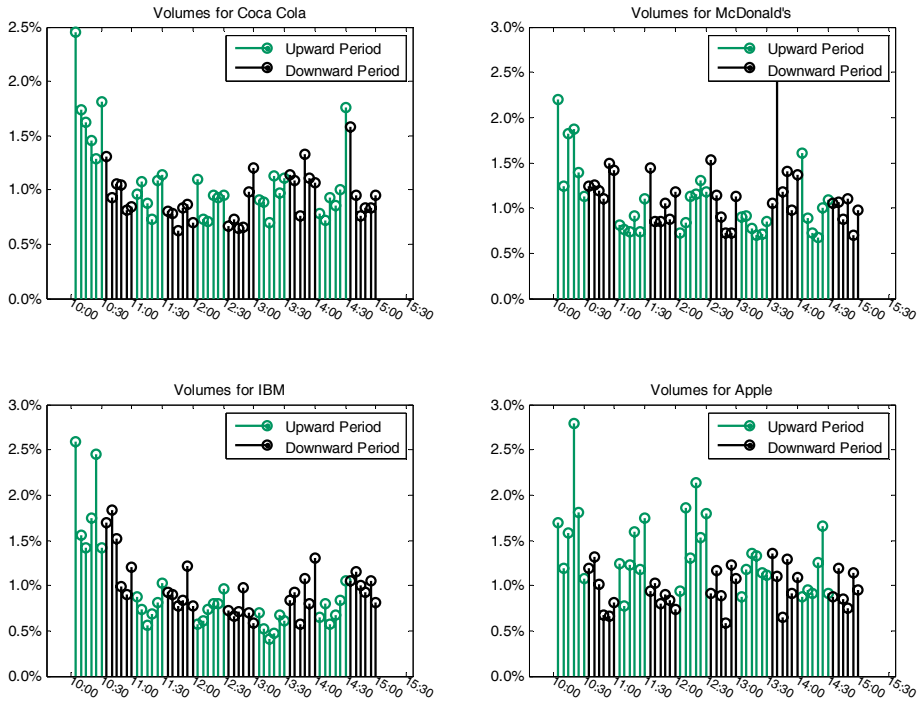
Source: Crédit Agricole Cheuvreux Quantitative Research

Market impact convexity explains why the VWAP of an upward (respectively downward) period is closer to the highest (resp. lowest) price

Instinctively, we expect trading volumes to be higher at the end of a period in order to produce such an effect. Indeed, it would pull the price to the extreme values. However, the volume proportions in FIGURE 14: did not confirm that. Indeed, no such pattern inside each period can be distinguished from the volume proportions.

Besides, we can also discard a winning strategy using a TWAP (time weighted average price) algorithm instead of VWAP. Indeed, a VWAP strategy with an almost uniform volume proportion curve is equivalent to a TWAP strategy.

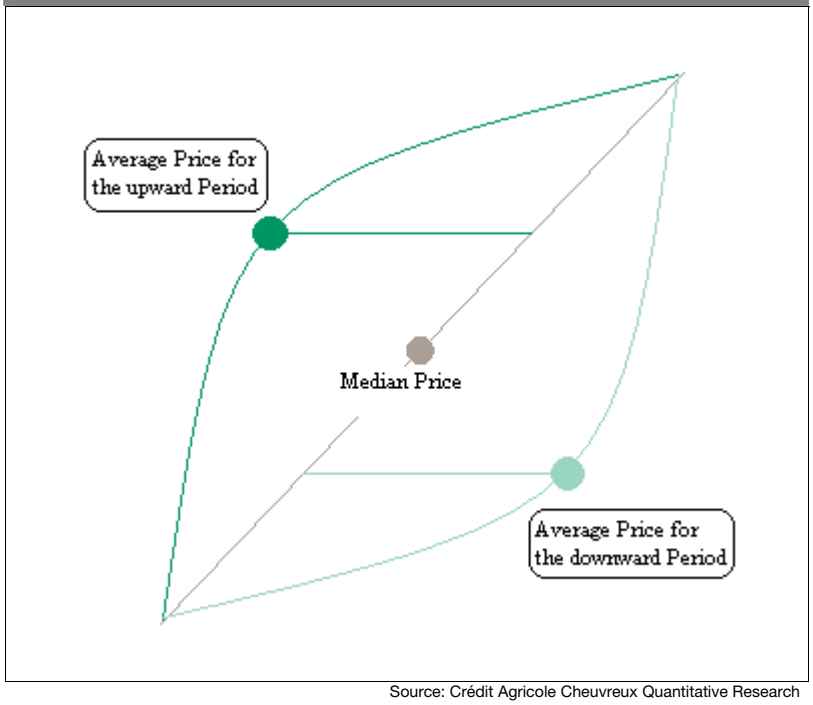
FIGURE 14: VOLUME PROPORTIONS



Source: Crédit Agricole Cheuvreux Quantitative Research

Finally, this asymmetry is due to the convexity of the price trajectory (concave in an upward period and convex in a downward one) caused by market impact. The VWAP (assuming a uniform volume proportion) being the median price of the curve, it is automatically deflected towards the extreme values, as shown in FIGURE 15: . The hypothesis of an intentional impact on price to make money out of the PFP (price formation process) seems to be irrelevant.

FIGURE 15: PRICE TRAJECTORY CONVEXITY AND VWAP



Source: Crédit Agricole Cheuvreux Quantitative Research

One agent selling and buying making money using other stocks

We have seen that an intraday strategy relying on one stock is clearly discredited as being the cause of the saw-tooth effect. Statistical arbitrage strategies could be responsible.

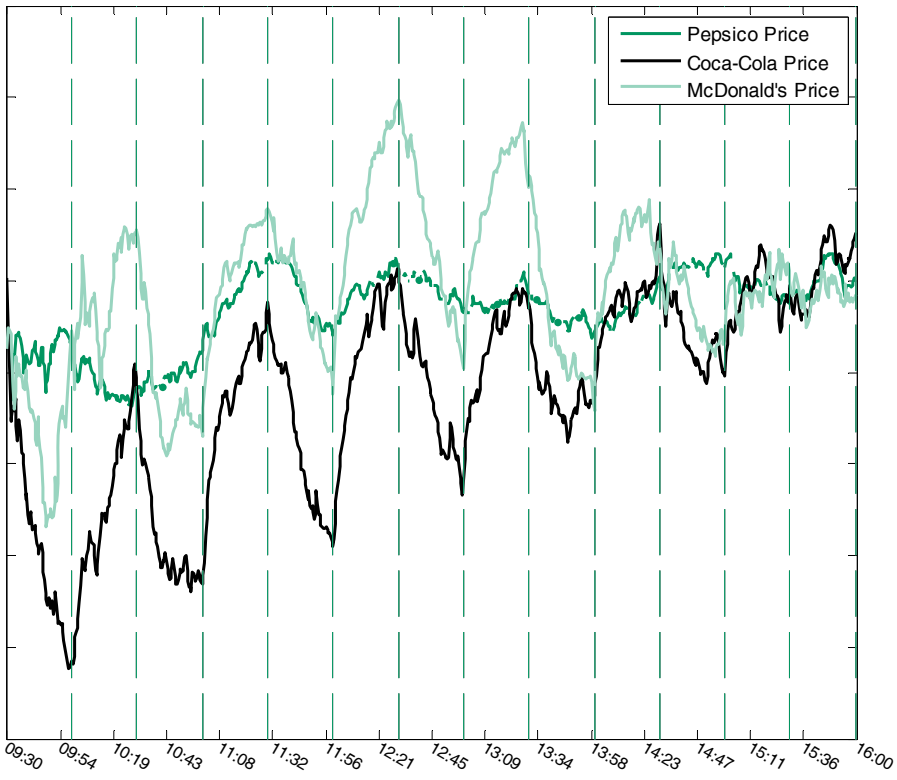
The very high correlation for the couples Coca-Cola/McDonald's and IBM/Apple (FIGURE 17:) raised the question about a possible lagged pair trading strategy. This strategy consists of simultaneously **buying IBM aggressively** and **selling Apple passively,** for example, in the upward period and simultaneously **selling IBM passively** and **buying Apple aggressively** in the downward period and repeating the cycle.

In FIGURE 17: , we present the intraday correlation on 19 July (marked positively, in grey) and the extraday correlation (marked, negatively, in black) between Coca-Cola (respectively IBM) and stocks of the S&P100. **We note that the four stocks are more correlated, by far, amongst each other than with other stocks**.

However, we also note that Coca-Cola and IBM, respectively, have more significant extraday correlation with other stocks than with McDonald's and Apple, respectively. For example, even though PepsiCo and Coca-Cola are economically correlated and have an extraday price correlation of 66%, larger than that for Coca-Cola and McDonald's at 59%, the price patterns of Coca-Cola and McDonald's on 19 July are similar and different from that for PepsiCo (see FIGURE 16:), **which tends to confirm that the pattern is not likely to correspond to a lagged pair trading strategy**.

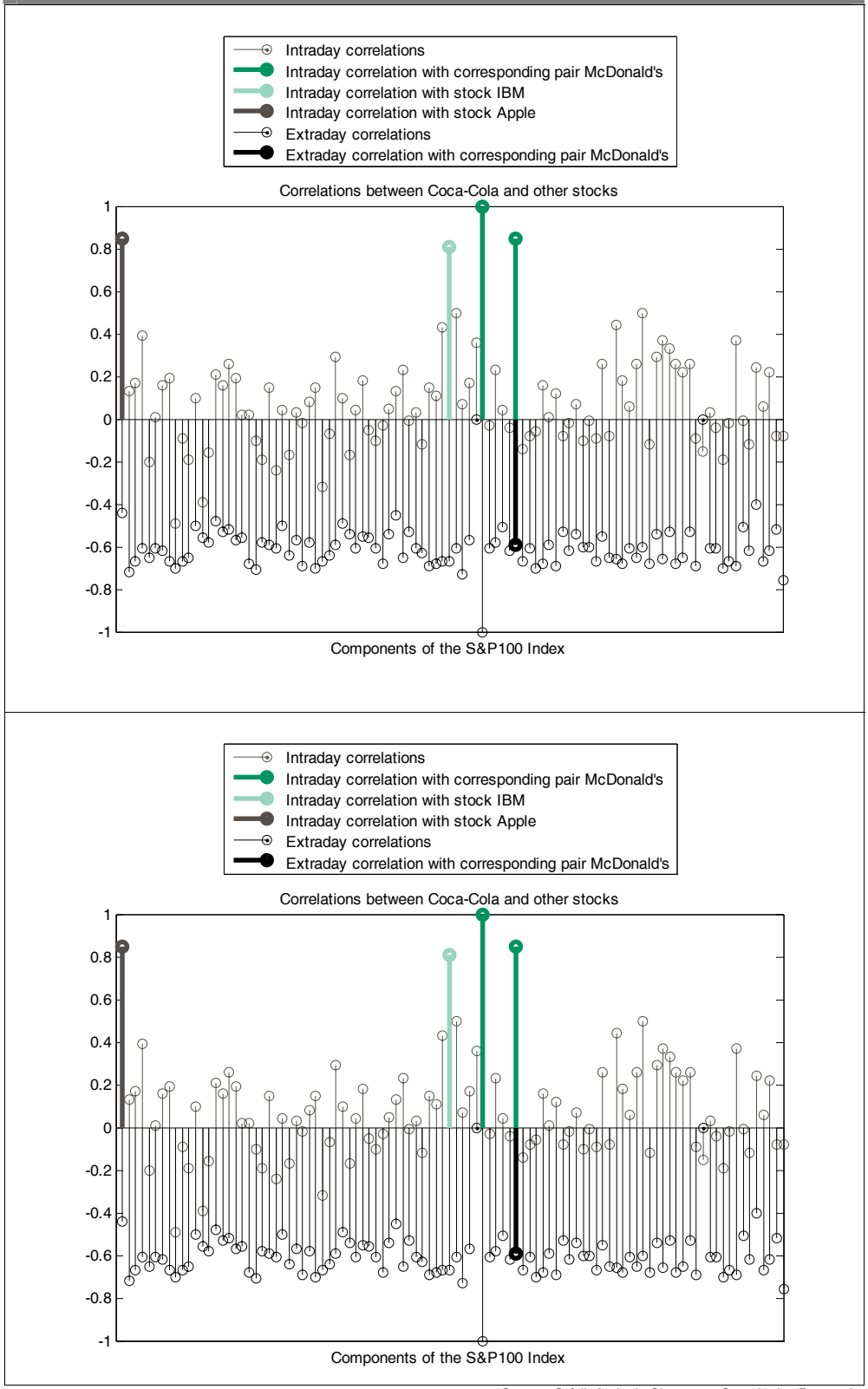
Conclusions of the two previous sections make it **unlikely that the pattern is produced by a statistical arbitrage strategy** consisting of buying some or all stocks concerned in an upward period and selling other or the same stocks in a downward period. We then need to examine the role of other financial instruments to find the strategy behind the pattern.

FIGURE 16: PRICE PATTERNS OF COCA-COLA, MCDONALD'S AND PEPSICO



Source: Crédit Agricole Cheuvreux Quantitative Research

FIGURE 17: COCA-COLA PRICE CORRELATIONS



Source: Crédit Agricole Cheuvreux Quantitative Research

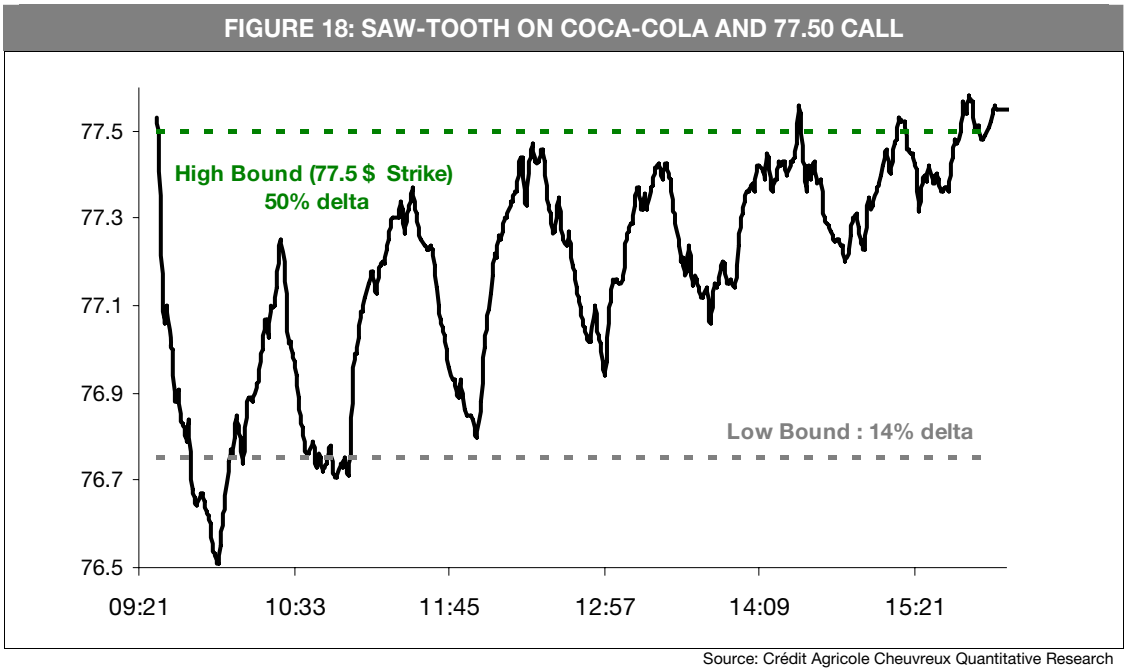
Repetitive delta hedging seems to be the most plausible explanation

Options stucturers and market-makers need to delta hedge their positions in order to offset their market exposure. So-called "dynamic hedging" flows can create strong selling or buying pressure, which might impact market prices. These flows can reduce or increase stock volatility depending on the hedgers' positions.

If market-makers are selling vanilla options to long-only managers, then dynamic hedging will tend to increase stock volatility. This phenomenon can be particularly strong when the options get close to maturity. Intuitively, this result can be understood by considering for example that a call option seller who delta hedges his position will have to buy stocks in order to deliver them to the option buyer. He will thus positively impact the underlying stock price. This behaviour cannot logically explain a price reversal.

Conversely, when market makers buy vanilla options from long only managers (through call overwriting for example), then dynamic hedging tends to reduce stock volatility. This phenomenon is called "pinning" for short-term options. Nevertheless, when open interests and the gamma are very large, hedging flow impacts can be very significant.

FIGURE 18: SAW-TOOTH ON COCA-COLA AND 77.50 CALL



Source: Crédit Agricole Cheuvreux Quantitative Research

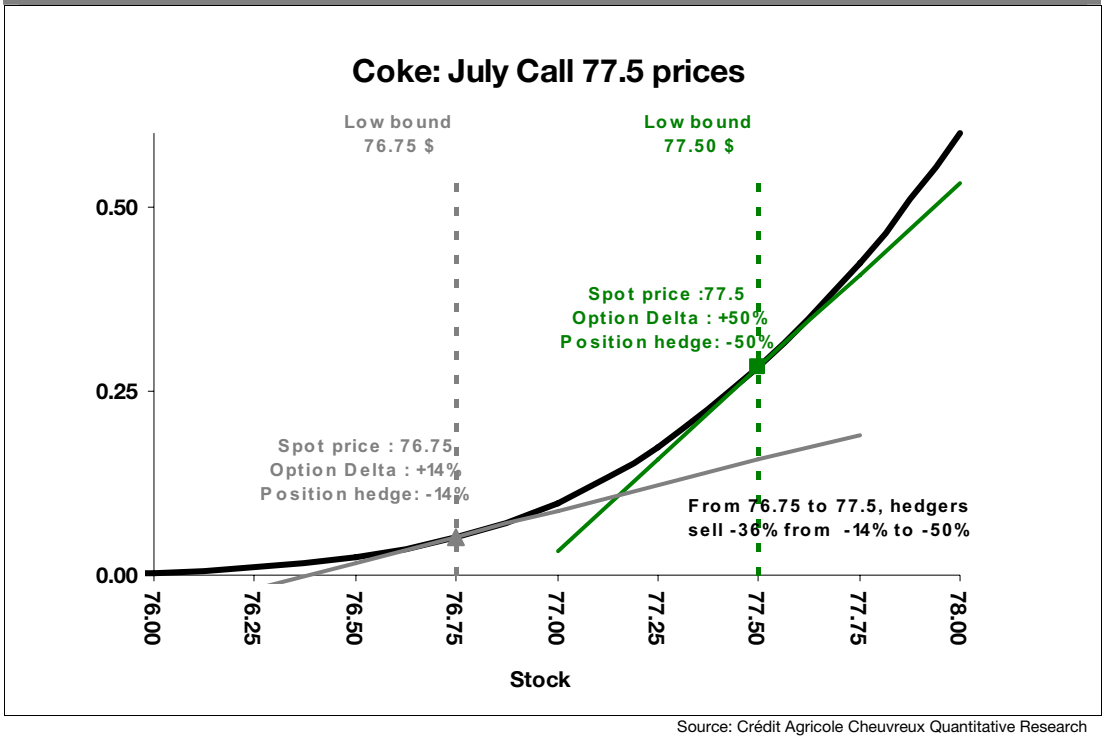
19 July 2012: the derivative hedging scenario

Consider Coca-Cola on 19 July (FIGURE 18 and FIGURE 19) the VWAP was 77.24. Large open interests (20 556) on the 77.5 July Call and on the 75 July Put (13 477) were observed. For a 1% price change on Coca-Cola, delta hedging of the total number of open interests would imply a trading of 1.1 million shares, 12% of the volume on 19 July. This particularly high number was due to three elements: **the size of the open positions, the fact that the stock trades next to the option strike, and the 1-day remaining maturity**.

On that particular day the price fluctuated 10 times, nearly every thirty minutes, with a 0.8% average move. Also, the traded volume amounted to 9.0 million shares. This means that the total hedging of those options would have represented nearly 100% of the total daily volume. This shows that delta-hedging can constitute a very large share of Coca-Cola's trading volume.
It is **important to note** that the total open interest on listed options does not necessarily imply that delta hedging will occur on this total underlying notional. The net delta hedging notional will correspond to the net volatility positions of the long only players. Usually long only funds will sell volatility through call overwriting, they could also buy volatility through calls or puts to take advantage of their directional views.

In qualitative terms, these counter-cyclical hedging flows can create a strong impact on prices. This situation has also been observed for McDonald's, IBM and Apple where sizes of open interests in listed options are large.

FIGURE 19: LONG VOLATILITY DELTA HEDGING



Source: Crédit Agricole Cheuvreux Quantitative Research

The reverting dynamic explained by a periodic operational process

While many farfetched explanations can be advanced for the "saw-tooth effect" on Coca-Cola, McDonald's, Apple and IBM. Adhering to the Occam's Razor principle, we favour this simple explanation: the sudden use of a rigid repetitive operational process for delta hedging these four stocks.

Suppose a trader has to follow an existing option book without having full real-time access to his monitoring and execution tool, or that he cannot dedicate all his time to this task and therefore chooses to monitor this book every thirty minutes.

Repetitive Delta hedging process

- **Step 1) t_0 = (initial time)**
  - Price the options, compute the delta on the new spot price
  - Evaluate the total amount of stocks needed for the delta hedge
  - Send the orders to the market.
- **Step 2): TWAP execution over 30 min**
- **Back to Step 1) t_1 = (initial time+30min)**

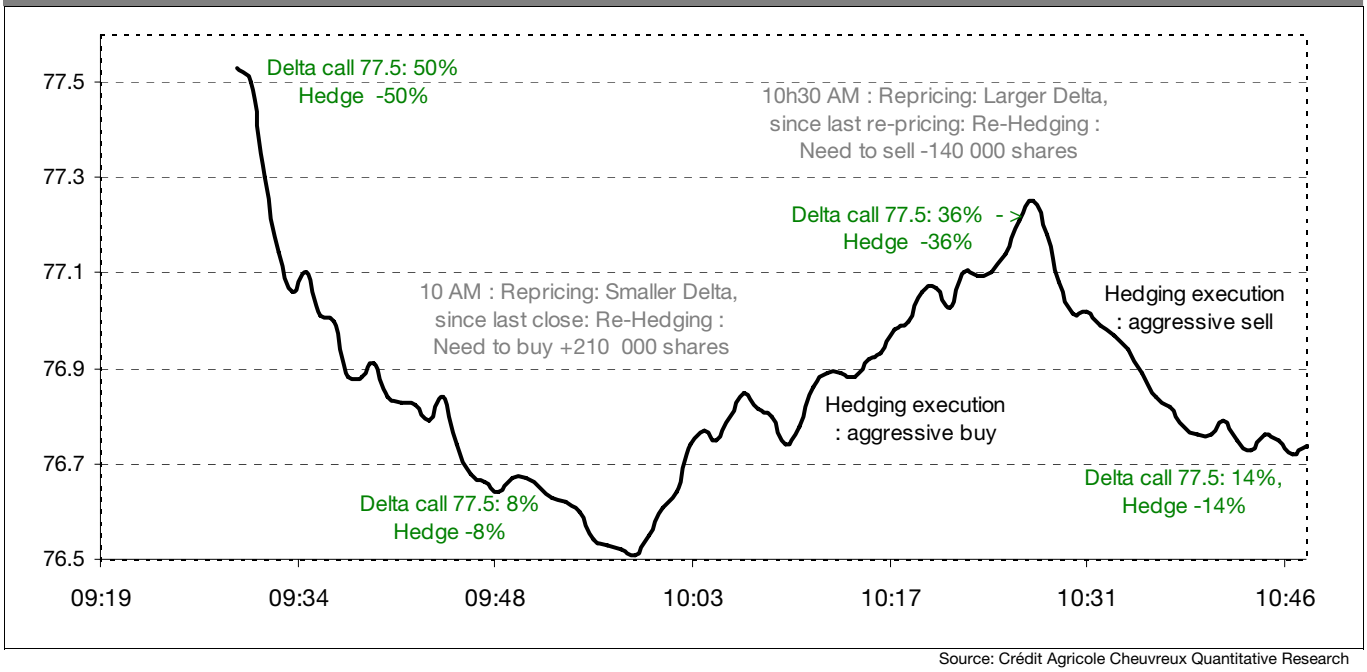
For a very large open interest position encompassing a large gamma, a significant move in the stock price will have disastrous effects for a basic rudimental hedger such as the one described above.

Illustration of this repetitive hedging process on a Coca-Cola saw-tooth

Suppose a market-maker owns 25% of the open interest on the 77.5 Call (FIGURE 20).

At 10 a.m. (New York Time) the market-maker will compute his delta and his hedge. Since the stock has dropped by 1.2% since yesterday's close, his delta has dropped from 50% to 8%. He realises he must buy 210,000 shares. This constitutes 30% of the past 30 minutes of trading on the stock. The trader decides to execute his hedge on a 30-min TWAP and buys the stock very aggressively. At 10:30 a.m. he realises its trading impact has pushed the stock 0.9% higher. His position is thus no longer market neutral. Now his delta is 36%, and he is hedged for 8% only. He realises he must sell 140,000 shares. Again this constitutes a large share of the current trading of Coca-Cola (22% of past 30-min volume). He decides to aggressively sell the stock on a 30-min TWAP. The stock price decreases by 0.70% due to the sell pressure, before the trader recomputes his delta…
This pattern repeats itself right up until the end of the trading day. The obvious solution to end this pattern is to change the trading behaviour. The key issue is to hedge options with synchronised real-time execution monitoring.

FIGURE 20: PERIODIC DELTA HEDGING PROCESS (COCA-COLA FROM 9.30 AM TO 10.50 AM)



Source: Crédit Agricole Cheuvreux Quantitative Research

The above chart represents price changes from 9:30 a.m. to 11:00 a.m. This constitutes the first two morning troughs. A total of seven troughs can be observed for the day as a whole. The very same mechanism takes place throughout trading until the market closes. Hence, this periodic hedging process clearly explains the saw-tooth observed on Coca-Cola during the day.

The three other stocks: The above explanation for Coca-Cola also applies to McDonald's, IBM and Apple.

For McDonald's, whose price fluctuated between 92.40 and 93.40, large positions were parked on the 90 and the 92.5 Calls as well as on the 90 Puts. A one-percent price change constituted the trading of 400,000 shares, 6.5% of the 3-Month average daily volume.

IBM's price was between 194.5 and 196.5, and there were large positions on the 190 and 195 Calls as well as on the 190 and 195 Puts. A one-percent price change constituted trading of 700 000 shares, 17.5% of the 3-Month average daily volume.

For Apple, prices were less stationary. The "saw-tooth" effect was mixed with an uptrend. Prices stayed below 615. Large options positions were parked on 610 and 615 strikes. A one-percent price change constituted trading of 1,000,000 shares, 6.8% of the 3-Month average daily volume.

We present a more detailed explanation in the table below (FIGURE 21), which illustrates the delta-hedging pressure on the four stocks at each peak of the saw-tooth pattern. We assume that for the two strikes closest to the money Calls and Puts of July 2012, the share of the delta hedged options stands at 100% of the open interest. This gives us theoretical maximum delta hedging flows.

Thanks to the volume analysis carried out initially that showed a 20-30% volume participation, we estimate that the real fraction of the hedged options of the four stocks ranged from 30% to 50%. For Apple, dynamic hedging seems to constitute a smaller portion of the volumes. This is consistent with the Apple's less-pronounced saw-tooth pattern.

FIGURE 21: PERIODIC DELTA HEDGING PROCESS ON 4 STOCKS ON JULY THE 19

100% Option hedging		Coke		Mac Donald's		IBM		Apple	
Sawtooth Timetable From	To	Price chg (%)	Gamma (Shares to trade)	Price chg (%)	Gamma (Shares to trade)	Price chg (%)	Gamma (Shares to trade)	Price chg (%)	Gamma (Shares to trade)
9:30 AM	10:00 AM	-1.2%	1 277 419	-0.4%	172 786	-0.8%	535 032	-0.7%	653 595
10:00 AM	10:30 AM	0.8%	-836 500	0.8%	-303 688	1.0%	-718 870	0.7%	-657 895
10:30 AM	11:00 AM	-0.8%	853 816	-0.6%	258 342	-1.0%	711 563	-0.3%	326 797
11:00 AM	11:30 AM	0.9%	-1 003 911	0.8%	-303 359	0.6%	-449 294	0.3%	-327 869
11:30 AM	12:00 PM	-0.8%	852 713	-0.5%	215 054	-0.6%	446 429	-0.2%	163 399
12:00 PM	12:30 PM	0.9%	-1 002 604	0.9%	-345 946	0.9%	-629 012	0.5%	-490 998
12:30 PM	1:00 PM	-0.8%	851 613	-0.8%	300 107	-0.8%	534 351	-0.3%	285 016
1:00 PM	1:30 PM	0.7%	-715 215	0.6%	-259 179	0.8%	-538 462	0.4%	-449 163
1:30 PM	2:00 PM	-0.4%	426 357	-0.8%	300 429	-0.8%	534 351	-0.4%	406 504
2:00 PM	2:30 PM	0.5%	-570 687	0.5%	-216 216	0.8%	-538 462	0.4%	-408 163
2:30 PM	3:00 PM	-0.4%	425 806	-0.4%	172 043	-0.8%	534 351	-0.4%	365 854
3:00 PM	3:30 PM	0.4%	-427 461	0.3%	-129 590	0.5%	-358 974	0.4%	-367 197
3:30 PM	4:00 PM	-0.1%	141 935	-0.2%	86 114	-0.5%	357 143	-0.2%	162 602
Total (Absolute nb of shares)			**9 386 039**		**3 062 853**		**6 886 293**		**5 065 052**
Hedging / daily volume (%)			**104%**		**41%**		**66%**		**32%**

Source: Crédit Agricole Cheuvreux Quantitative Research

When the gamma is very large and the hedging process very crude, stock pinning can even forge a saw-tooth effect

On a very short-term maturity, large delta hedging concentrated around specific strikes can impact prices. When some delta hedgers represent a large share of the open interest, this phenomenon can be very significant. This is what academics call "pinning", it should drive prices back to their strikes. Nevertheless, **when delta hedging is combined with a simplistic execution process "pinning" can degenerate into "saw-tooth" effects**.

Simplistic hedging of large gamma options is a plausible explanation for the "saw-tooth" trading pattern. This explanation is consistent with the main features of this phenomenon: timing, aggressiveness, impact, predictability and information leakage which is what characterises those "saw-tooth" patterns. Fortunately, large option positions are most often managed dynamically in a continuous way, and discrete archaic hedging processes have almost disappeared in modern-day markets.

IV— Execution style matters in an highly fragmented market

The use of an over-simplistic hedging algorithm on these four stocks on 19 July demonstrates important features of the price formation process:

- **US orderbooks are not able to provide resistance to a crude aggressive algorithm** trading around 30% of the average daily volume, even if this is not an unusual volume variation.
- **There is no perfect "Market Impact Model", as each trading style impacts the price a different way.** As we showed in *Navigating Liquidity 6*, market impact is essentially a matter of timing at any scale: is the portfolio manager a trend follower or a mean-reverter? Is the algorithm buying very aggressively and in such a visible way that other automated market participants do not offer any resistance to it? Or is the algorithm utilising a more subtle strategy based on boundaries of participation rates combined with opportunistic liquidity seeking tactics?
- Pattern matching techniques, market impact models, and order flow imbalance measurements, using **anonymous tick-by-tick databases can detect such crude and regular behaviour**.
- **The fragmentation of equity markets, in conjunction with the rise of predatory high frequency trading, makes orderbooks less resistant to unexpected moves**: who will take the risk of not following such an aggressive trading pattern? Certainly not brokerage algorithms (even "Implementation Shortfall" has to incorporate "signals" to avoid being adversely selected by HFTs in common conditions; what else than a signal would be such a liquidity taking event?), and clearly not HF market-makers, with their very small inventories.

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