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 **Foresight**

Computer based trading, liquidity and trading costs

**The Future of Computer Trading in Financial Markets - Foresight
Driver Review – DR 5**

Contents

Executive summary.....	4
Computer-Based Trading, Liquidity and Trading Costs	6
Understanding CBT	6
The current trading landscape: UK equities and Foreign Exchange markets.....	8
Foreign Exchange market.....	11
Equities versus Forex	12
The rise of Computer-Based Trading.....	13
Computer-Based Trading and market activity.....	14
Recent trends in UK stock liquidity	21
Order flow redistribution across stock classes.....	25
Is CBT still growing?	29
Risks generated by CBT and areas for further research	30
CBT and fragmentation.....	32
Concluding comments	34
References.....	35

Computer based trading, liquidity and trading costs

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31st August 2011

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¹ Department of Accounting and Finance, University of Bristol, and Cass Business School, respectively. We thank two anonymous reviewers for their comments. For fruitful discussions, we also thank Aneel Keswani, Ian Marsh, Sébastien Pouget and Ian Tonks, as well as high-frequency traders or market-makers at Citadel, Credit Suisse, Flow Traders, HSBC, Knight Securities and Susquehanna.

Executive summary

We aim to supply evidence on the effect that the development of Computer-Based Trading (CBT) has had on broad measures of activity and liquidity in the UK equity market. In particular,

1. In the time series, is there evidence that CBT is still growing or has it reached equilibrium penetration in the post crisis trading environment?
2. In the cross-section, how does use of CBT differ across large, mid-cap and smaller stocks? Is there evidence that computer-driven trading has drawn trading interest and liquidity away from smaller issues?

We find that:

- As a simple indicator of the appearance and growth of CBT, the expressions 'Algorithmic trading' and 'High-frequency trading' have become widely used in the specialized UK press from 2005 and 2009, respectively.
- CBT seems to have had profound effects on trading activity:
 - The average trade size has exhibited a continuous decline from 2006 till 2009 on both LSE and Euronext.
 - In UK large and mid caps, average trade size today is less than *one third* its level of five years ago.
 - These effects are strongly cross-sectional: they are much less pronounced for small capitalization stocks.
 - Trading on alternative order-driven venues such as Chi-X and BATS exhibits the same patterns.
 - Evidence is consistent with these venues receiving a greater proportion of their order flow from algorithms than does the historical exchange.
- Liquidity in the post-crisis period has improved for large caps but not for smaller issues.
- Trading interest in smaller stocks may have suffered from the growth in CBT.
- The decline in trade size that we linked to the growth in CBT appears to have stopped. This holds for the LSE, other UK trading venues and Euronext, and it is consistent with a period of fast CBT growth having come to an end.
 - Consistently with this interpretation, evidence from interviews and appearing in the specialised press indicates that the current growth areas for computer-driven trading lie outside of equity markets and the marginal profitability of computer-based strategies has declined.

The main features of the UK trading environment have been comparatively stable since the second quarter of 2009. Any significant shifts to these features (e.g. a return of high volatility) may cause further shifts to computer-driven activity.

We also discuss the penetration of CBT in Foreign Exchange markets relative to that in stock markets.

Finally, we suggest areas of risk or uncertainty associated with CBT that we feel should be investigated. These areas include the effect of CBT on volatility, on market depth and other dimensions of liquidity, and the roles and incentives of exchanges with respect to High-Frequency traders.

Computer-Based Trading, Liquidity and Trading Costs

Computer-based trading (CBT) today appears to perform many of the roles that human traders have previously fulfilled. It even seems to excel at those functions where human skills were thought most important such as market-making and ‘worked’ order execution. This Review will address the question: *what does the development of CBT mean for turnover and liquidity across large, mid and small caps?*

In contrast to extant studies of computer trading, this Review will not contribute a micro-econometric analysis based on stock-level high-frequency data but, on the contrary, attempt to document the ways in which the trading environment has been altered by CBT over a long period and at a high level of aggregation. Although some of our statistics will be constructed from high-frequency data, we will report evidence based upon monthly or yearly frequencies of observation and at index or whole market levels of measurement.

As part of its contributions, this Review aims to paint a broad picture of the past decade of trading developments *with a specific focus on the UK equity market*. To our knowledge, there are no academic studies of CBT based on UK stock data. The Review will have a secondary focus on the Foreign Exchange (FX) market, itself consisting to a significant extent of deals that are done in London. For lack of hard data, analysis in that area consists of survey evidence generated elsewhere though we will also draw from interviews of London-based FX traders we have conducted.

We will start out with tentative definitions of these new trading practices, and attempt to pinpoint the development of CBT in the UK market. A question running through this Section will be whether the extant typologies of traders and trading strategies have been blurred or made irrelevant because algorithmic and high-frequency trading have given rise to new types of market participants and to new forms of risk.

We will then turn to description of the impact that the recent growth in CBT has had on turnover and liquidity at a very aggregated level of measurement and over a long period.

This Review will argue that a key question to answer is whether computer-based trading may now have run its course in terms of the changes it has caused to the trading environment. We will report preliminary evidence consistent with this interpretation using some very recent data. We acknowledge that this equilibrium may not be stable with respect to shifts in the trading environment (e.g. a return to the levels of volatility seen in 2008, or a shift in trading demands or trading protocols).

Finally, we will discuss the risks to liquidity and asset pricing that we feel are most significant and the areas where our understanding of CBT is currently most wanting.

The question that is beyond the remit of this Review is what effect CBT at its current or future levels has on market outcomes, and whether the extent of its use should be left to market forces as it has been up until now.

Understanding CBT

This section seeks to place some structure on our discussion of CBT by delineating the different but overlapping groups that agents conducting CBT may belong to.

Schwartz (2010) argues that dark trading has existed for decades. In the same way, most of the strategies that have been mentioned in the HFT debate are nothing new, even if they are now being executed using better technology and at greater speed. 'Flash quotes' used to be known as 'stealth' or 'fleeting' orders, human brokers have used 'worked' order execution to minimise market impact for a long time, and specialised funds have implemented order anticipation strategies, now more often described as 'predatory', to exploit predictable order flows, only at lower frequencies. CBT may have allowed some of these strategies to develop to an extent that has become problematic, but we feel that traditional economic typologies retain their relevance when it comes to analyzing them.

As a starting prior, the extensive use of computer scripts in trading is a way to make the tasks previously performed by humans both less expensive and more efficient (e.g. through faster quote adjustment to news). If CBT has contributed something genuinely new to markets, it is arguably a type of participant loosely called the "HFT shop": using computing power and programming skills, small outfits have been able to compete effectively with the largest 'sell-side' firms. This has made brokerage and market making services more competitive and 'contestable', which most economists would feel is welcome in an industry that is notoriously dominated by a small number of very large brokers.²

Microstructure and market organisation theories suggest three key dimensions along which computer-based trading strategies can be discriminated.

1. *Agency activity versus proprietary trading*;
 - a. Agency flow or execution flow: CBT which executes customer orders in an agency capacity over a negotiated period of time against a pre-determined performance benchmark.³
 - b. Proprietary flow: CBT which does not seek to execute orders that have been independently formulated by clients, but which takes positions or places orders solely to profit from short run price and/or liquidity fluctuations.
2. *Liquidity-consuming strategies versus liquidity-supplying tactics*;
 - a. Aggressive, liquidity-consuming strategies trade at the prices offered by other agents.
 - b. Liquidity-supplying strategies offer prices at which others may trade. As such, they provide (at least partial) market-making services without regulatory obligation or reward.
3. *Informed versus uninformed traders*;
 - a. High-frequency informed traders (believe themselves to) have predictive ability over very short-term returns. Such forecasting power may be derived, for example,

² A June 2010 financial consultancy report finds that the top 5 brokers in the US command a market share of equity trading of close to 9% each. ("Greenwich Share and Quality Leaders: U.S. Equities", Greenwich Associates, June 2010.) Again for the U.S., Wall Street and Technology, Dec 19, 2008, similarly indicates that "According to recent research from TABB Group, 13 core brokers currently receive 72 percent of the buy-side flow." Academic evidence reveals similar concentration on the market-making side. For a large sample of Nasdaq stocks, with Chung and co-authors, JFI 2006 reporting that "The top five dealers account for more than two-thirds of the total volume".

³ These benchmarks may be based on prices or volume (or many other market metrics). An example of a price based benchmark is the Volume Weighted Average Price (VWAP) benchmark. Here the executor of the order has his performance judged through comparison of the execution price with the VWAP over the order's lifetime. An example of a volume based benchmark is a participation-based one, where the executor is instructed to trade so as to be a particular fraction of volume (e.g. 1%) until the order is complete.

from identifying mispricings across assets or markets, from being able to exploit order book imbalances or from being able to forecast the future trading intentions of others. This final mechanism for forecasting is often called 'order anticipation' or 'predatory trading'.

- b. Uninformed traders are not trying to exploit high frequency predictable variation in returns but are rebalancing their portfolios for other reasons. A classic example would be of a mutual fund which has experienced an outflow of money trading so as to liquidate part of its portfolio. Note that high-frequency uninformed traders may be trading on long term information. They may neither know nor care where prices are moving in the next few seconds, but believe that they are able to judge where prices will be in six months.

The preceding set of definitions serve to illustrate how diverse CBT is: different types of CBT can be found which correspond to many of the permutations of the above features.

- For example, the majority of the early CBT models traded agency flow in an aggressive fashion but without any particular high-frequency information advantage.

The class of modern CBT which seems to worry regulators most is that which falls into the informed, aggressive and proprietary class. The scope of such flow is far from clear though, and there is currently little or no evidence regarding whether and to whom it causes significant losses.

The current trading landscape: UK equities and Foreign Exchange markets

Alongside a typology of CBT, one also needs to understand the environment that such traders inhabit. The interaction between the trading environment and the actions of traders yields the market outcomes (prices and quantities) that we observe. The environment is formed by the set of venues that are available for trade.

Over the last decade, indeed in the last few years in Europe, this trading landscape has changed dramatically with new trading venues opening, others closing and many altering the nature of the trading service they offer.⁴ Below we offer an overview of the landscape for two of the major asset classes that are relevant to the UK: British listed equities and foreign exchange.⁵

UK equity markets

- From 1986 till late 1997, trading in London equities was *quote-driven*: brokers could observe the bid and offer quotes posted on an electronic display system by market-makers in each stock. Trades of any economic significance were then concluded over the

⁴ For example, some exchanges or trading facilities may alter their fee structures to reflect the changing nature of their customer bases. Others have changed their IT infrastructure to make themselves more attractive to certain types of market participant.

⁵ As the 2010 BIS report makes clear, London has cemented its position as the globe's dominant FX trading venue.

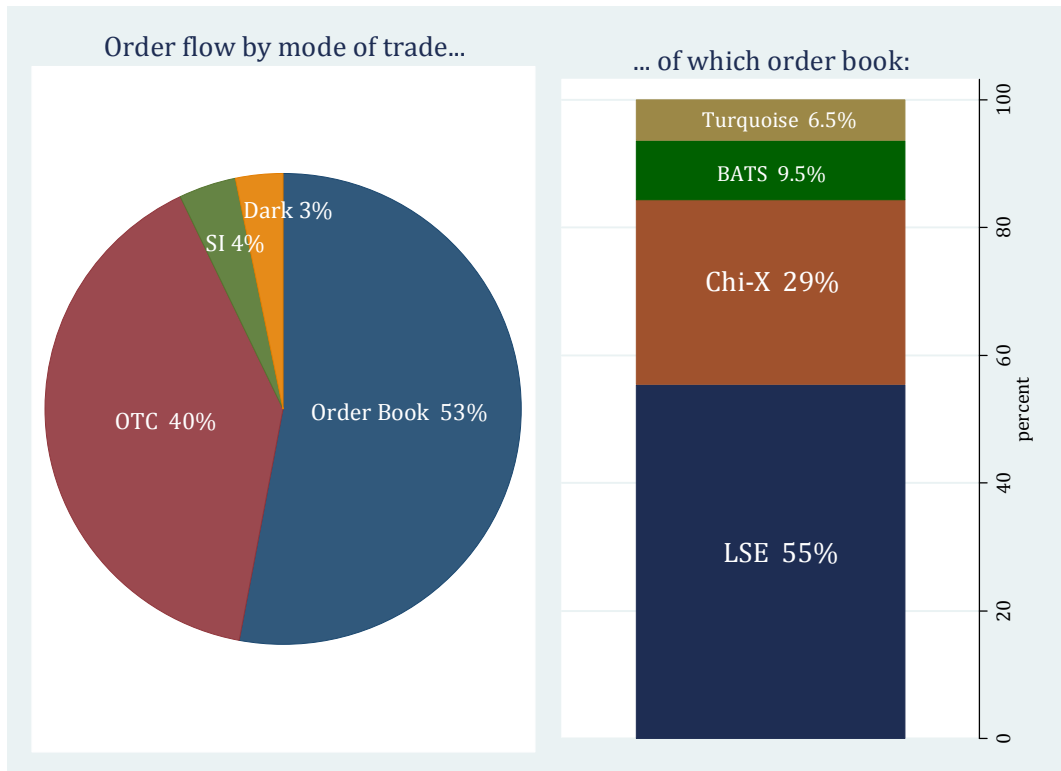
phone (no automated execution). A key feature of that system was that market-makers had regulatory obligations to supply liquidity.

- In October 1997, the LSE introduced *order-driven* trading to the UK market with its electronic order book called SETS, where buy and sell orders of traders could be matched directly. At the same time though, significant amounts of activity remained dealt “at risk”, that is, bilaterally negotiated with broker-dealers off the order book (Friederich and Payne, 2007). Post-1997, there were no designated agents with obligation to supply liquidity for SETS stocks.
- Since 2007, other venues structured as electronic order books have emerged. Chi-X was first (July 2007), BATS and Turquoise followed about a year later. They captured significant market share. (Chi-X and BATS have agreed to merge in May 2011 as corporate entities, although separate trading systems will remain.)
- More recently, several firms have launched “Dark Pools” - venues to which clients may submit buy or sell orders that are not displayed to the market at large (the total sizes and the limit prices of orders are concealed from other users).
- The EU “Markets in Financial Instruments Directive” has forced those brokers who internally match a significant amount of client orders to be identified as “Systematic Internalisers” (SI), considering that they effectively provide a trading service.

Trading on the London market thus includes four different modes of trade, given for FTSE-100 stocks in the left panel of Figure 1 below:

FIGURE 1: BREAKDOWN OF ORDER FLOW IN FTSE 100 STOCKS

BY TYPE OF EXECUTION, Q1/2011 (GBP VALUE)



The key divide is between electronic and dealer-based trading. The former comprises order book and 'Dark Pool' order flow, while the latter includes OTC and 'Systematic Internaliser' business. We discuss them in turn:

1. Multilateral, transparent electronic order books.⁶ Their market shares by sterling value traded are given in the right panel of Fig. 1.
 - The dominant venue remains the LSE's SETS system, an electronic limit order book of the type found in all mature markets.
 - There is competition from other order-driven venues with very similar microstructures to SETS but perhaps different fee structures or trading latency.
2. Dark pools (DPs)
 - Alternative execution venues, some run by exchanges and some by banks.
 - These are also multilateral in nature but have greatly reduced pre transparency of buy and sell orders. This is to reduce the adverse price movements associated with exposing one's orders to the market.
 - DPs are said to be preferred by large, uninformed traders who fear predation or "order anticipation" by proprietary CBT systems if they were to submit their orders to a transparent limit order book.
 - In London as in the rest of Europe, DPs currently attract a small fraction of total order flow. This is unlike the US market, where figures between 10 and 20% have been reported.

⁶ This is sometimes referred to as 'lit' trading, although 'lit' is a misnomer given that hidden or 'iceberg' orders are extensively used in order book trading.

3. Bilateral trade with dealers
 - Liquidity is provided voluntarily by stock dealers in investment banks. There are no obligations on dealers to provide such liquidity and they receive no regulatory rewards for doing so. Much of this activity is today reported as dealt “Over the Counter” (OTC) but it can also be conducted “on exchange” (in the graph above, this turnover is included with OTC trading).
4. Systematic internalisers match order flow against their inventory or match the orders of clients directly. They also represent a small proportion of total activity.

Note that the numbers given in Fig. 1 overstate the amount of trading that is conducted OTC (Over the Counter) because of double reporting of certain types of trades.⁷ A point to keep in mind for our purposes is that by its nature, Computer-Based Trading can only be conducted on electronic order books and to some extent on Dark Pools. Therefore the fact that over 40% of all order flow remains traded off those venues places an upper limit on CBT and should remind us that brokers and their clients retain a choice of execution modes.

Foreign Exchange market

The spot Forex (FX) market is a global, 24 hour market.⁸ An enormous number of currencies can be traded, although most trades involve a small set of currency pairs drawn amongst the US Dollar, the Euro, the Yen, the British Pound and the Swiss Franc.

The market is decentralised (or fragmented) both in order flow and in informational terms – that is, each order book or dealer only sees the order flow that they receive, and there is no ‘ticker tape’ or other consolidated means of post-trade dissemination of information as there is for stocks. However, a significant proportion of the volume traded in this market is conducted through London-based dealers. The Bank of International Settlements (BIS) (2010) suggests that London has the largest market share of any financial centre in spot FX trading. It is worth noting that FX markets became electronic later than did equity markets. Thus, while one sees similar structure to equity markets, dealers still hold a more central position in FX.

The Forex trading landscape has the following main features:

- Transparent order-driven trading
 - EBS and Reuters offer order book trading which were originally for inter-dealer trade only but now allow CBT from hedge funds. For example, EBS allowed algorithmic trading in 2004 and allowed hedge funds to trade via their prime brokers electronically in 2005.
 - The Chicago Mercantile Exchange offers order book trading in FX futures which can be accessed by algorithms and computer-based traders. Algorithmic access was first allowed in 2002.
 - Other smaller systems exist (Currenex, Hotspot, FXAll).
- Bilateral trade with and between dealers
 - Trades can be concluded with dealers over the phone or via computer systems (e.g. Thomson Reuters’s systems). This is similar to equity dealer flow, except that it is totally opaque (i.e. trades are neither systematically reported to regulators nor published).

⁷ A recent report by AFME (2011) considers that the true amount of OTC trading is much lower but the validity of some of the corrections they suggest is debatable. We feel that their figures are in turn an understatement.

⁸ ‘Spot’ means ‘cash’, as opposed to ‘derivative’.

- Certain banks provide electronic systems which guarantee two-way liquidity, 24 hours a day in major currencies for pre-screened clients who may include customers and other banks (e.g. Deutsche Bank's Autobahn, Citi's Velocity).
- Dark pools
 - Exist in the currency world also. BGC partners and others provide dark execution capabilities, though with limited penetration so far.
- Retail aggregators:
 - Firms that aggregate FX quotes from financial institutions and match these quotes with incoming retail order flow.
 - Such firms may also supply liquidity themselves.

Therefore the key distinction between dealer-based and electronic trading is apparent in Forex trading just like it is in equities. Foreign Exchange trading has increased dramatically since 2004 (see BIS 2010 and 2007). The most recent BIS survey shows that the trader class where most growth has occurred is 'Other financial institutions'. This class comprises hedge fund and currency fund order flow.

King and Rime (2011) argue that it is the activity of hedge funds and retail investors (the latter through the retail aggregators mentioned above) that is really behind the growth in FX trading, and that the majority of this flow comes from CBT. They argue, for example, that as of 2009, over 50% of total spot FX activity is electronic and that the share of algorithmic volume on EBS is estimated to have grown from 2% to 45% between 2004 and 2010.

Equities versus Forex

Interviews conducted with FX and equity traders in the City of London for the purposes of this Review suggest the following key similarities and differences between equities and FX trading:

- Both FX and equity flows have become increasingly based on CBT. (See, for example, the figures quoted earlier on the extent of algorithmic trading on EBS.)
- Penetration of algorithmic, dynamic *agency* flow on multilateral order books in FX is *small relative to that in equity markets*. There are some providers of such services in the FX world (most notably Credit Suisse through their AES product), but they are far less important in volume terms than similar flows in equities.
 - Why? Perhaps the natural depth of currency markets makes it easier to satisfy regular trading demands quickly and at (or close to) the best price, removing the need for dynamic execution.
- Thus, some of our interviewees suggested that relative to equity markets, CBT in FX markets was more likely to be proprietary activity, rather than execution of agency flow.
- Dealer-based relationships are still very important in the FX market, whether through direct personal communication between dealers and clients or through single bank electronic systems. Banks are still actively making markets in FX to a much larger extent than in equities.
- Fragmentation has occurred in both equities and FX. There is a multiplicity of providers of limit order book trading in equities as in FX.

The rise of Computer-Based Trading

How much of total trading can be considered computer-driven?

There is no clear answer to this most basic question, because there is no simple definition of what constitutes CBT, and no dataset that can claim to isolate it unambiguously. Private sector consultancies like the Tabb Group estimate the incidence of High-Frequency trading specifically at 38% for Europe and 54% for the US in 2010 (Cited in *Financial Times*, 12 April 2011). Other figures have appeared. The Wall Street Journal, 25 April 2011, states that “66% of global stock trading is high frequency.” (Note that discrepancies between figures can be due to the fact that some are expressed as proportions of order book trading and other as proportions of total trading.)

When did CBT become significant?

Our first concern is to attempt to pinpoint when CBT became an object of significant interest on the part of UK industry and investors. This is important for our purposes because we propose to study trends using data going back several years.

As a simple way to get clues, we searched the electronic databases of two financial newspapers -- the weekly industry paper the *Financial News* as well as the daily *Financial Times* -- for the keywords “Algorithmic trading” and “High-Frequency trading”.⁹ These searches yielded the following number of hits, sorted by year:

FIGURE 2A: NUMBER OF SEARCH HITS IN THE *FINANCIAL NEWS*
FOR CBT REGULAR EXPRESSIONS SINCE 2000

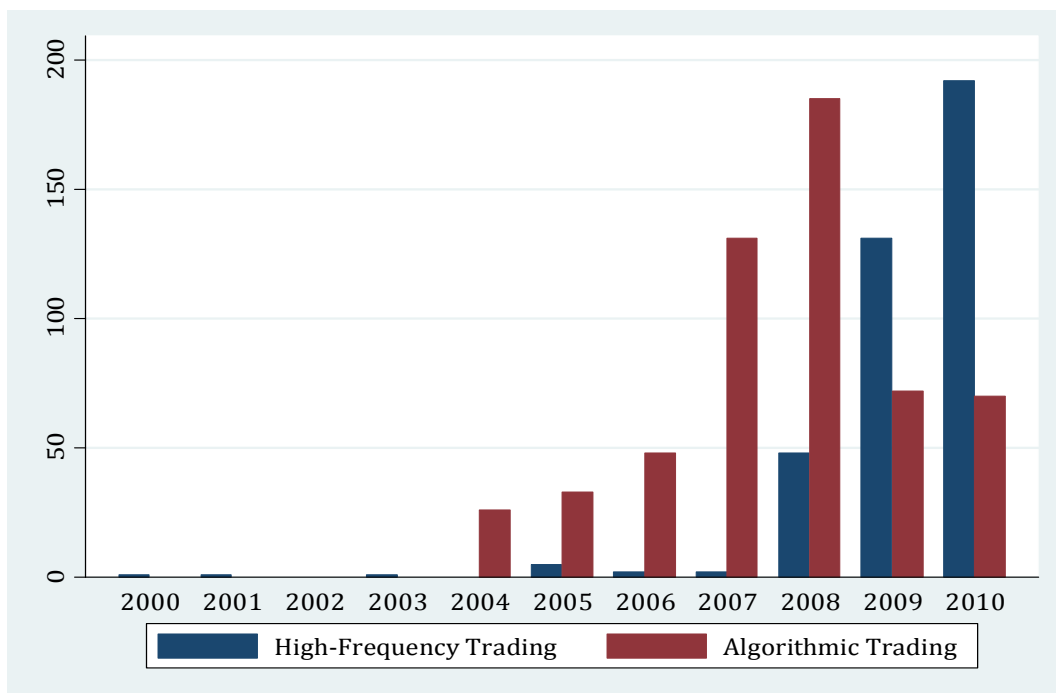
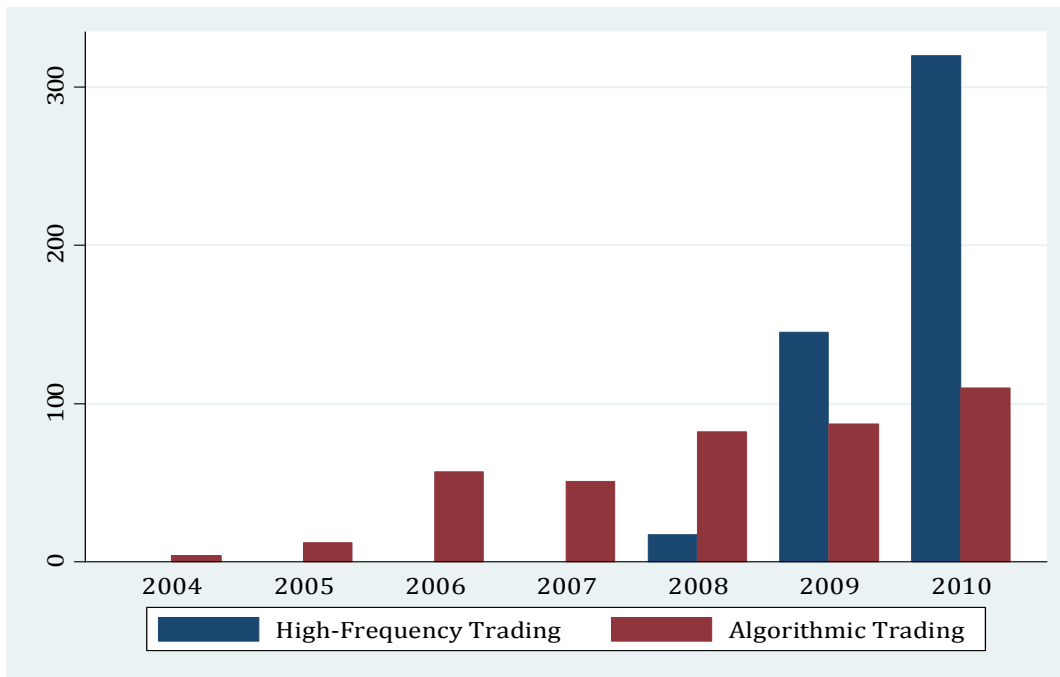


FIGURE 2B: NUMBER OF SEARCH HITS IN THE *FINANCIAL TIMES*

⁹ In a similar way, the newspaper *The Economist* constructs its “R index” from the frequency of occurrence of the word “recession” in the press to determine the presence and strength of an economic recession.

FOR CBT REGULAR EXPRESSIONS SINCE 2004



Although the databases have a different start date, the results in Figures 2A and 2B tell a broadly similar story: the regular expression “Algorithmic Trading” started registering in 2004-05, whilst “High-Frequency Trading” has appeared later, round 2008-09. The search hit frequencies also show that since then, HFT has received much more attention than the broader expression of “Algorithmic Trading”, the use of which now seems to be stalling (*Financial Times*) or on the wane (*Financial News*). (This leaves open the question of whether “High-frequency” has essentially replaced “Algorithmic” trading or whether they have genuinely distinct meanings in the minds of those who use these expressions.)

For our purposes, these results clearly indicate that, in the long-term trends that we study below, our focus should be on the period since 2005.

Computer-Based Trading and market activity

In this Section, we aim to give a sense of how trading has changed in the UK equity markets over the last decade or so. In particular, this Section aims to document the impact that the development of Computer-Based Trading has had on some of the most basic measures of market turnover. We do not attempt to provide an overview of extant academic research here. The interested reader is referred to Biais and Woolley (2011).

The results we present below were constructed by combining low and high-frequency data from multiple sources: The London Stock Exchange, Euronext, Chi-X, the World Federation of Exchanges, the Federation of European Stock Exchanges, Markit BOAT, Fidessa and Reuters. We focus exclusively on London-traded equities that are components of the set of FTSE stock indices.^{10,11}

¹⁰ To the reader unfamiliar with these data issues, we point out that comprehensive data are not available for the foreign exchange market. We can only refer to survey evidence such as that discussed in the paper by King and Rime (2011) mentioned above.

CBT and trading activity on order books

Figure 3 below comprises two panels that respectively show the total value and frequency of trades conducted in FTSE 100 stocks in every month since the start of 2006. We constructed the series by aggregating turnover across all electronic venues. (Specifically, they include trades occurring on the order books of the London Stock Exchange, Chi-X, BATS and Turquoise. We ignored smaller venues as they all have less than 1% market shares each.)

The Figures are consistent with HFT growing significantly since that time. They are also consistent with the “qualitative” analysis of the number of internet hits above which shows marked growth since the mid-2000s. Since January 2006, and even allowing for a drop off in trading activity after the worst of the market ‘meltdown’ that ended in Q1 of 2009, the monthly number of trades in FTSE-100 stocks has *more than quintupled*, while value traded has only increased by around 25%. It seems that most of the run-up occurred before and during the market crisis.

FIGURE 3A: VALUE TRADED ON ALL ORDER BOOKS: FTSE 100 STOCKS, 2006-2011

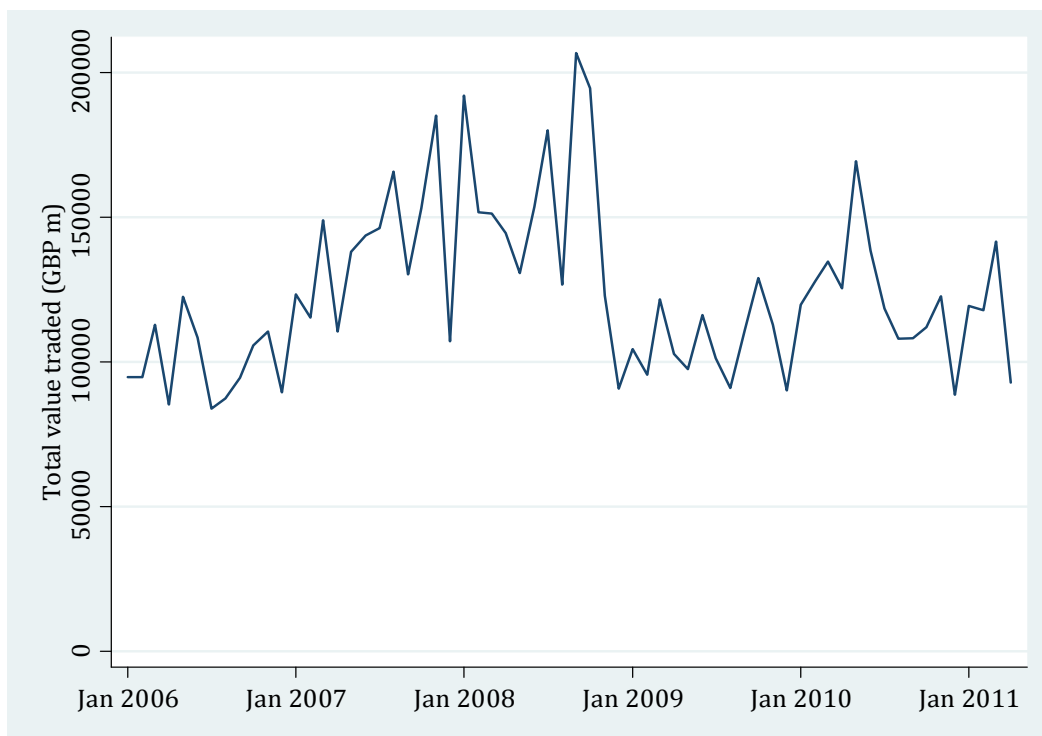
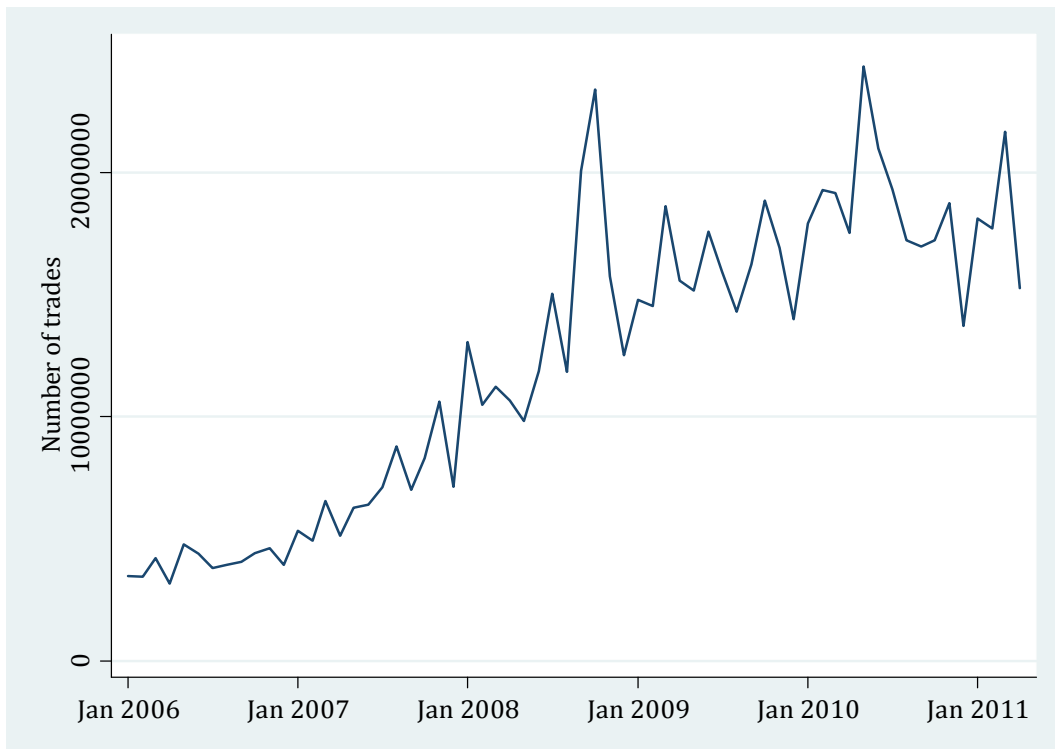


FIGURE 3B: NUMBER OF TRADES ON ALL ORDER BOOKS: FTSE 100 STOCKS, 2006-2011

¹¹ The equity indices are: the FTSE 100 and FTSE 250 indices, which broadly comprise large and mid caps respectively, and the FT-Small Cap index which, as its name indicates, includes smaller listed companies, although not the smallest ones, which in turn make up the FTSE Fledgling index. In terms of component numbers, the FTSE 100 and 250 comprise about 100 and 250 stocks respectively (actually slightly more), and the FTSE Small Cap includes about 270 companies. In this study, we do not include analysis of the FTSE Fledgling members because they represent an extremely small proportion of total trading interest (less than 1%).



Turnover in FTSE Small Cap stocks exhibits very different patterns (Figures 4A and 4B). Over much of 2010, trading frequency in small caps was similar to what it was four years before (with trading value somewhat depressed). Turnover by value traded and by number of trades have remained 'in step' for those stocks whereas they've experienced a 'decoupling' in large caps. To illustrate with a very simple statistic, over the period January 2006 – April 2011, the correlation between the monthly value traded and the frequency of trades is 0.843 in Small Caps while it is 0.296 in FTSE 100 stocks. Therefore, our results are consistent with CBT affecting the most liquid names proportionately more than small caps.

FIGURE 4A: TOTAL VALUE TRADED ON ALL ORDER BOOKS:

FTSE SMALL CAP STOCKS, 2006-2011

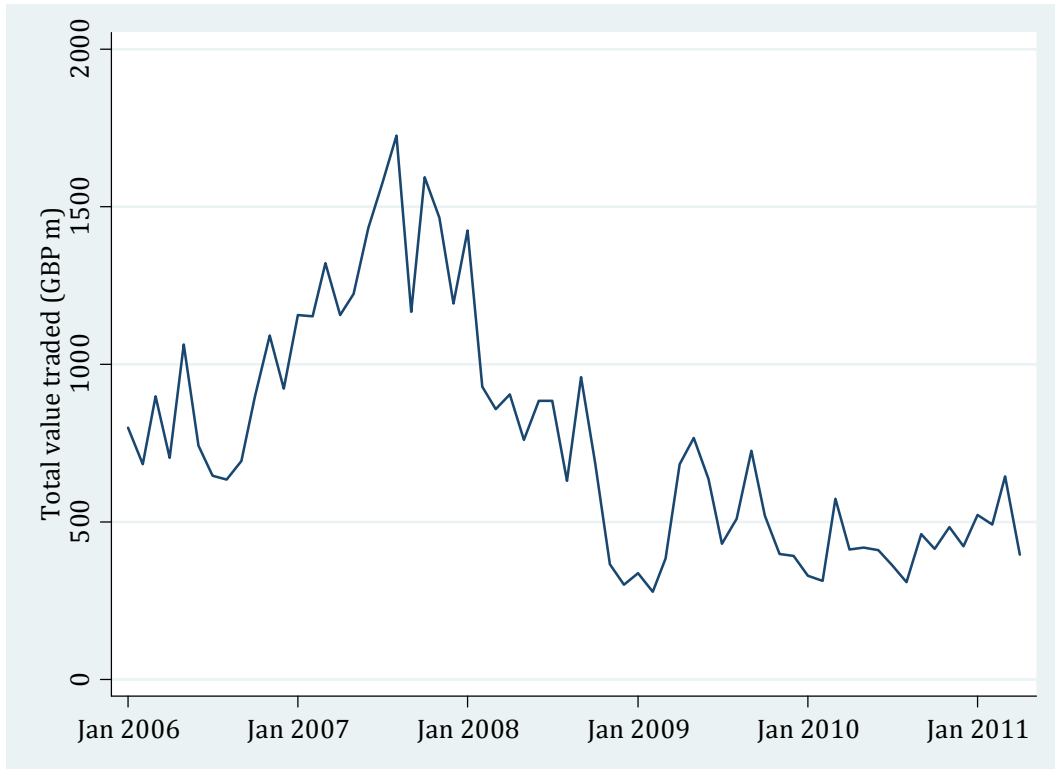
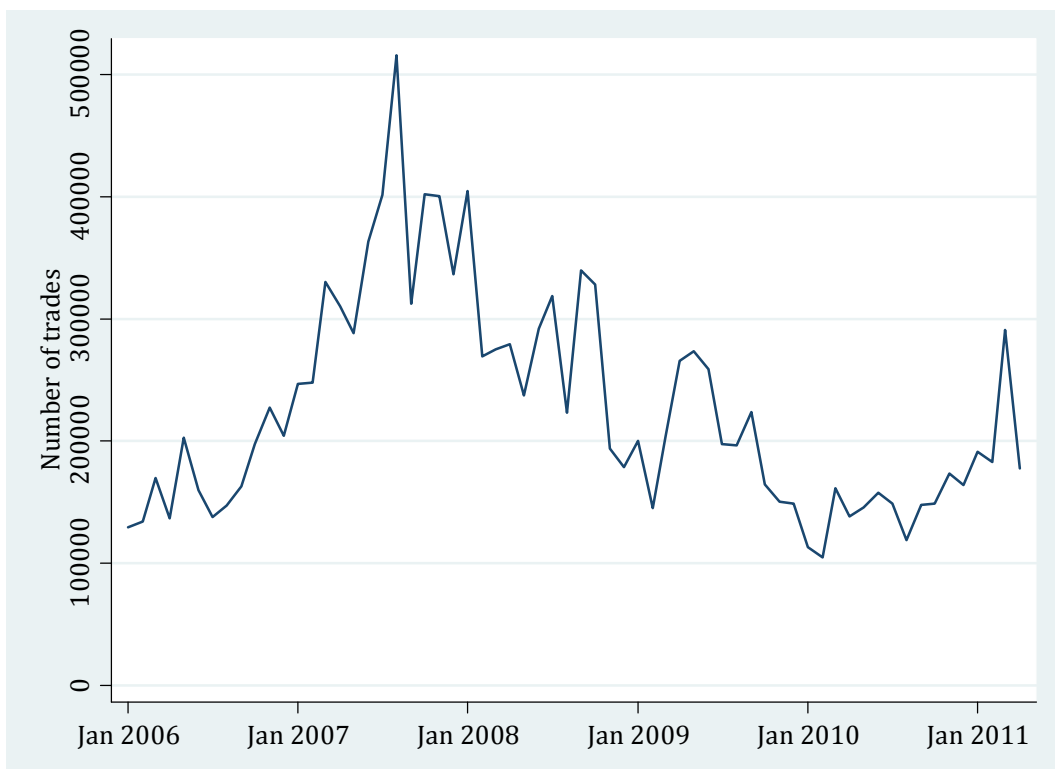


FIGURE 4B: NUMBER OF TRADES ON ALL ORDER BOOKS:

FTSE SMALL CAP STOCKS, 2006-2011



Trade Size

Figure 5 below compares the average value of transactions conducted on the London and Euronext order books since 2002 (across all stocks traded on these order books).

The patterns are quite similar: trade sizes dropped in 2007-08. As a result, average trade sizes are today less than a third of what they were not ten years ago. In London, trade sizes have more than halved since 2006.

FIGURE 5: LSE AND EURONEXT AVERAGE ORDER BOOK TRADE SIZE (GBP): 2002-2010

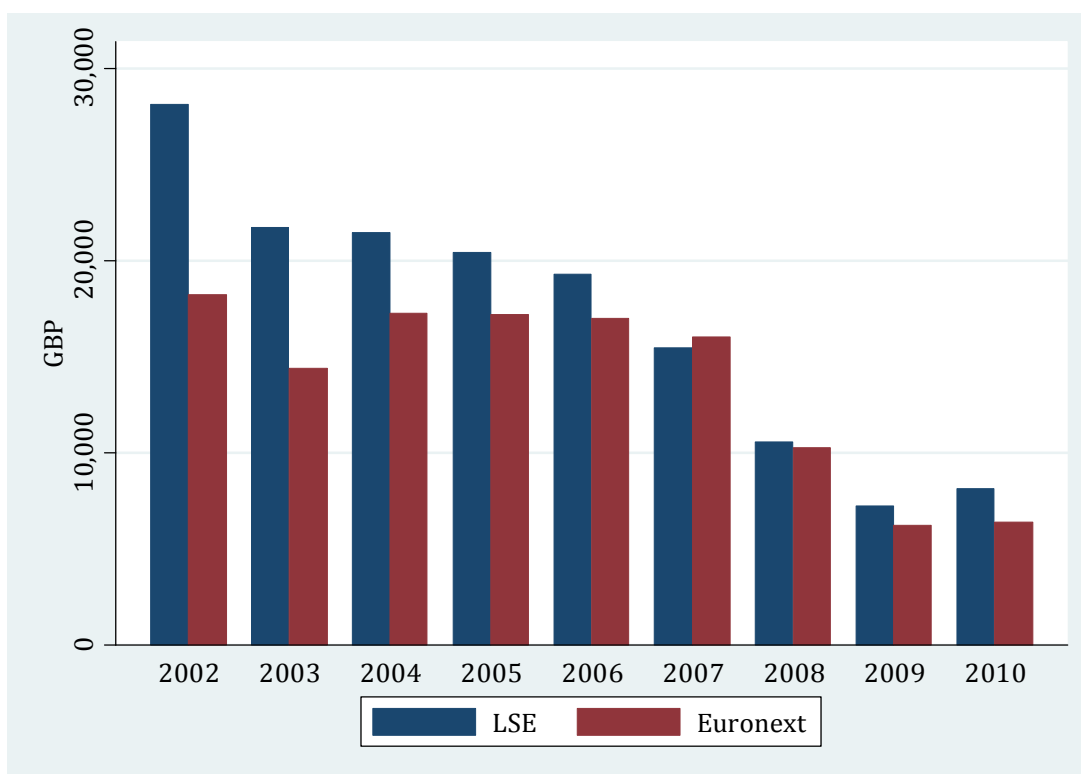
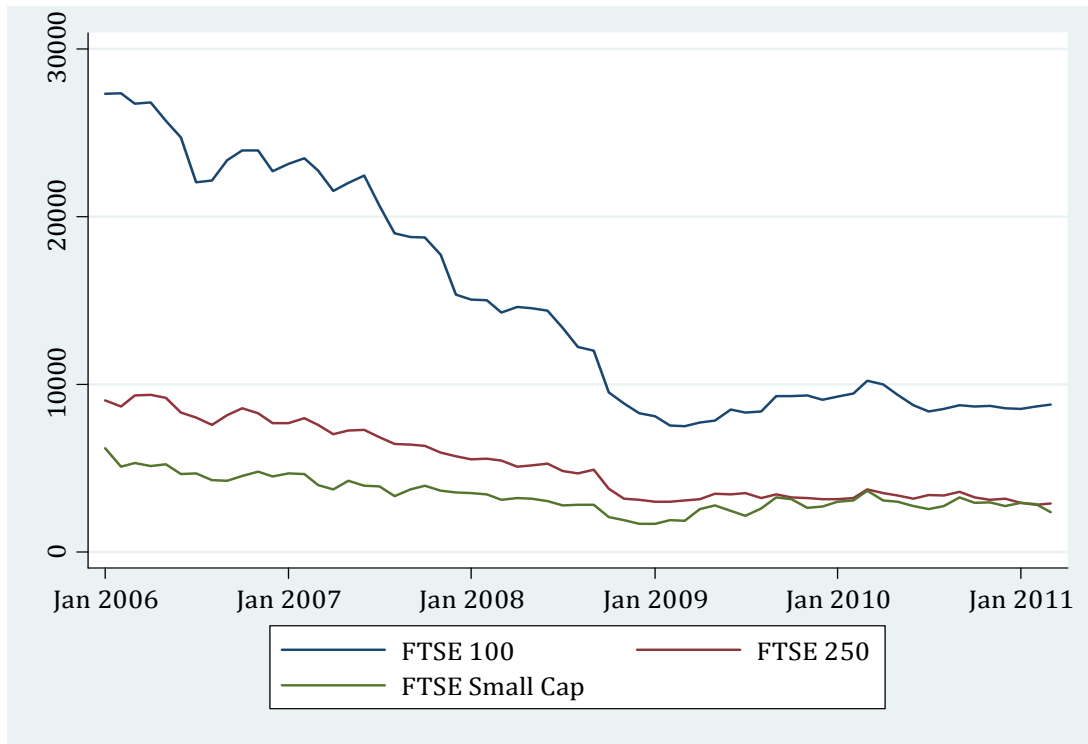


Figure 6 below depicts average trade size on the LSE's order book again but it is constructed using monthly data and shows London-listed equities grouped by index (large, mid and small caps).

FIGURE 6: LSE ORDER BOOK AVERAGE TRADE SIZE (GBP):

LARGE, MID AND SMALL CAPS, 2006-2011



This Figure shows that the reduction in average trade value observed in Fig. 5 has a clear cross-sectional component: a very strong decline is evident for FTSE 100 stocks and while it is also present in small caps, it is proportionately less pronounced. The average trade size in mid cap FTSE 250 stocks, which was over 50% larger than that of small caps in 2006, has gradually become similar to it. The gap between large caps and other stocks has remained constant since the beginning of 2009.

The large average trade size in FTSE 100 stocks at the start of the sample period is evidence that these securities are the focus of most institutional investment.

Arguably, the most remarkable aspect of these trends is that trade sizes continued to trend down through the extreme market conditions that occurred around the middle of this sample period. As a reminder, Figure A in the Appendix to this document depicts movements in the FTSE 100 index over the same period as Figure 5; Figure B in the Appendix shows movements in the “VFTSE” index, a tool designed to capture *expectations* of volatility on the part of market participants, sometimes called the “Fear Index” in the popular press for that reason. (The expectations of the market with respect to volatility may or may not materialise. Thus this index is distinct from a measure of realised, historical volatility). That the process of average trade size decline remained undisturbed by levels of activity (Fig. 3), volatility and investor risk aversion only experienced a few times in a century is an indication of how powerful and profound the effect of CBT has been on execution strategies.

We do not see which forces other than the growth in CBT could explain these trends. They can't be attributed to order flow fragmentation since they predate the development of alternative trading venues to the LSE: the first one to be launched, Chi-X, started trading FTSE 100 stocks in July 2007 and did not attract significant order flow before 2008. They do not coincide either with revisions to the exchanges' fee structures or to back-office costs, which would in any case be likely to have a sharper effect and not cause the very protracted decline that we observe.

Another common feature to Figures 4, 5 and 6 is that the trends they depict appear to have levelled off since the start of 2009. We note that this stability predates the end of the financial crisis by perhaps six months, but also and intriguingly, that it coincides roughly with the use of the expression 'High-Frequency Trading' becoming widespread, if newspaper frequency of occurrence is a reliable guide (Fig. 2).

The decrease in trade sizes could be driven by changes in either or both of the liquidity demand and supply sizes:

- On the demand side, order execution algorithms are designed to minimise market impact. This implies using fractioned, dynamic execution
- On the supply side, market-marking algos are designed to avoid suffering losses from 'toxic' order flow, whether because it's better informed or just based on 'order anticipation'. This may cause a reduction of their quoted sizes. Brogaard (2010) finds that HF traders do not contribute significant depth compared to non-HFT agents.

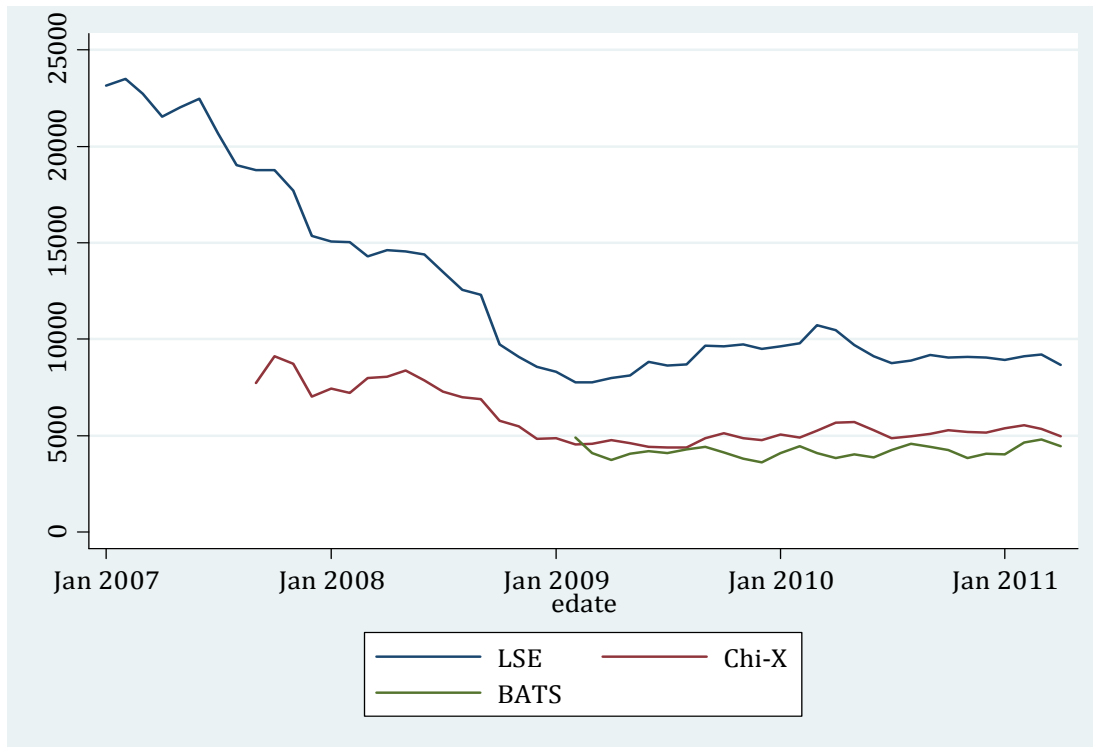
Going back to the question we asked in the introduction, there is evidence of HFT reaching limits that are imposed by technical constraints (such as those on latency) or deep trading demands such as the need for immediacy of execution in sizes that computer-based market-making can't offer. HFT may have reached an equilibrium penetration into London and Euronext equity trading, given the more stable and competitive trading environment that has prevailed since the second quarter of 2009. More work is required to confirm these results.

As another indication that these trends really have to do with the development of CBT, we turn to comparison between the LSE and its main electronic competitors in UK stocks. The trading venues that have appeared recently have directed their commercial efforts at the HFT community by emphasising low latency and HFT-friendly fee structures. If much of the order flow they attract is computer-driven and if the extent of CBT affects trade sizes, these venues should exhibit smaller trade size than the LSE.

This is exactly what one finds. Figure 7 compares the same trends for the LSE and its main competitors, the order-driven venues Chi-X and BATS that have appeared in July 2007 and October 2008 respectively.¹²

¹² They are called "Multilateral Trading Facilities" or MTFs in MiFID speak. We omit Turquoise, a smaller player now owned by the LSE, as well as any smaller venue.

FIGURE 7: AVERAGE GBP VALUE OF ORDER BOOK TRADES IN
FTSE 100 STOCKS: LSE, CHI-X AND BATS, 2006- 2011



This picture is consistent with the prior that the new electronic markets Chi-X and BATS cater for the trading needs of the HFT community much more exclusively than does the historical exchange. Even though the gap has narrowed, the average size of trades executed on the MTFs is smaller than that executed on the LSE by close to 50% for Chi-X and by over 50% for BATS.

- This suggests that the historical exchange has retained a much more diversified clientele of traders. This may be the result of liquidity considerations (the LSE's order book is likely still to be the deepest), MTF fee structures designed to attract HFT flow, and of other institutional factors: anecdotal evidence exists of broker execution policies specifying that the historical exchange should be the default execution venue for at least certain types of orders or clients.

Note finally that this Figure implies that the decline in average trade size since 2006 for the LSE only that is depicted in Fig. 6 is understated. Including trades from all order books would reveal a steeper decline affecting large and mid caps. It would not materially affect small caps as they are barely traded on order-driven venues other than the LSE.

Recent trends in UK stock liquidity

Figures 8 and 9 supply evidence on long-term changes in trading costs in London for three classes of shares, and thus give a sense of how liquidity in them has altered.

We computed mean and median inside spreads, and mean and median GBP quoted depth at the inside quotes from January 2009 till April 2011. The pictures show results for FTSE 100 stocks. (FTSE 250 stocks are not shown to save space, they exhibit similar patterns.)

FIGURE 8: LSE ORDER BOOK BEST SPREADS IN FTSE 100 STOCKS

(BASIS POINTS), 2009- 2011

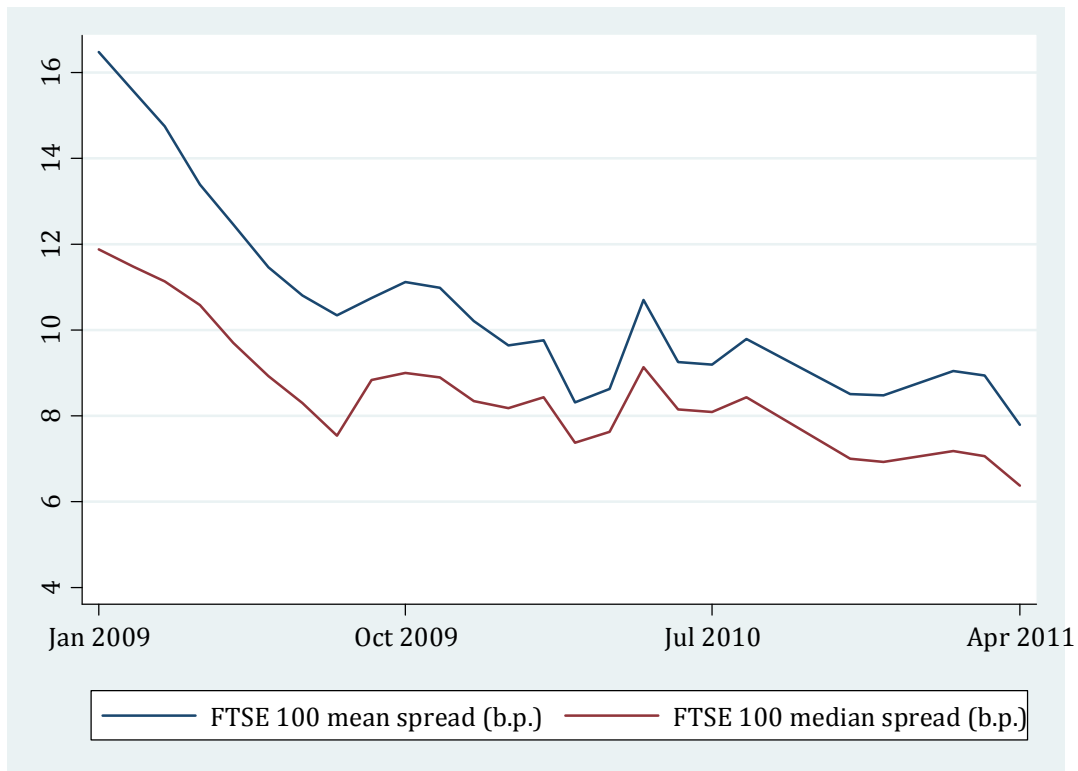
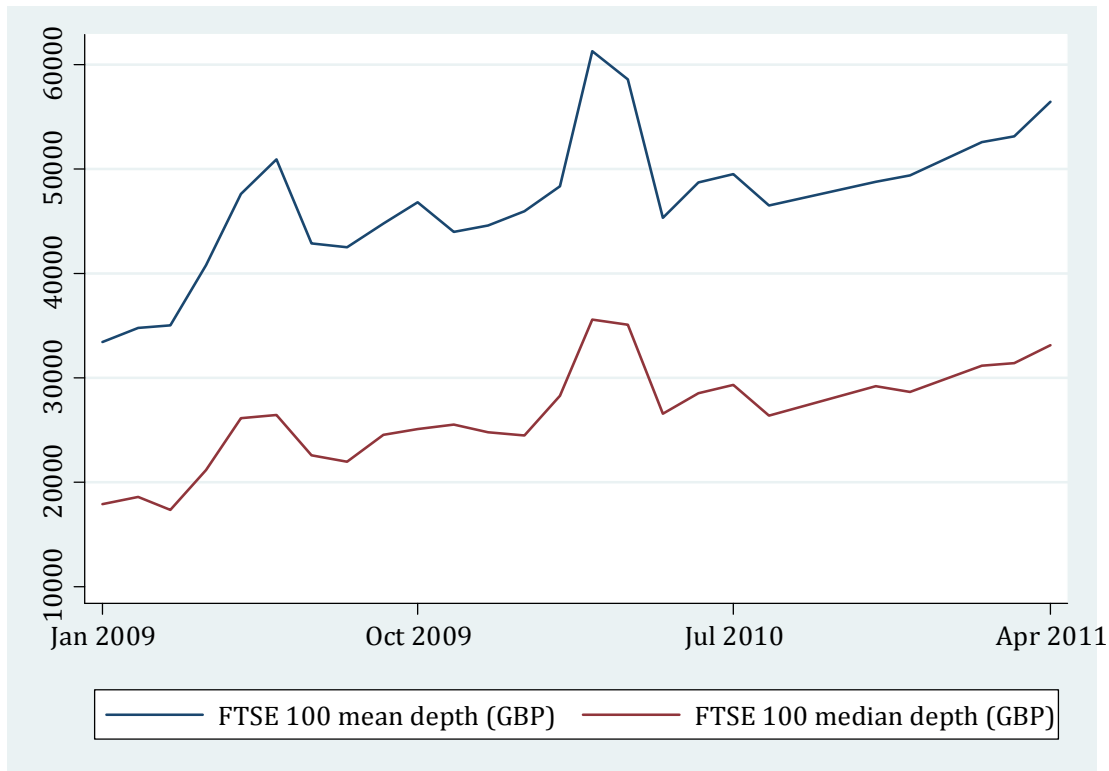


FIGURE 9: LSE ORDER BOOK DEPTH AVAILABLE AT THE BEST QUOTES,
(GBP) FTSE 100 STOCKS, 2009- 2011



The pictures show a clear downward trend in spreads and an equally clear upward trend in depth. If we had observed narrowing spreads accompanied by declining depth, with both potentially attributable to HFT, we might doubt whether liquidity had improved. That doesn't seem to be the case. We can also note that if the decline in trade sizes observed in Figures 5, 6 and 7 had resulted from declining depth at the quotes before 2009, then a reversion of this trend would have occurred since.

The improving liquidity in large caps seems to broadly coincide with the use of High-Frequency Trading becoming widespread (as noted in Figure 2, and if newspaper frequency of occurrence is a reliable guide). Equivalently, the effect of HFT on liquidity over that period had been at least of second order compared to the decline in extreme investor risk aversion.

Figures 10 and 11 below produce the same evidence but this time for Small Cap stocks, where HFT is comparatively marginal. They exhibit no obvious trend.

Two caveats must be noted:

- We observed before that the trade size patterns were consistent with most of the economic effect of HFT having already been incorporated by the start of 2009. Therefore a negative impact of HFT growth on depth could occur before the sample period covered in Figures 8 and 9. (We do not have the necessary data at this stage).
- Note further that our analysis says nothing about depth beyond the best quotes, whether displayed or hidden.

FIGURE 10: LSE ORDER BOOK BEST SPREADS IN FTSE SMALL CAP STOCKS
(BASIS POINTS), 2009- 2011

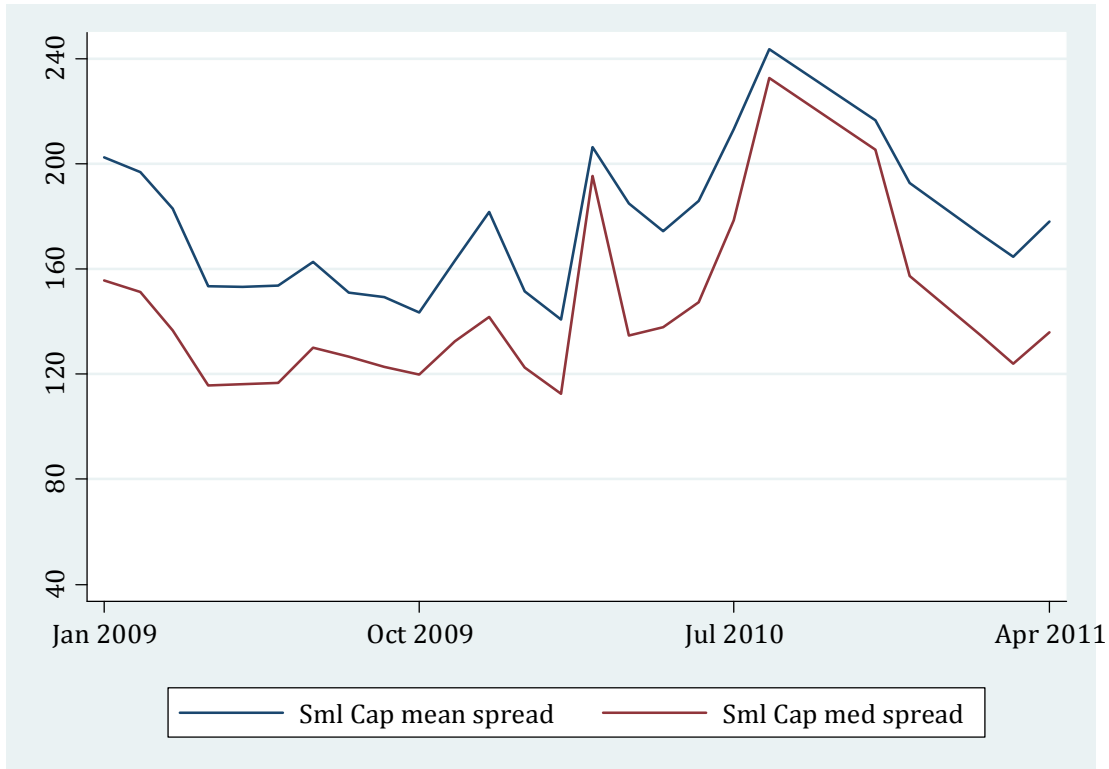
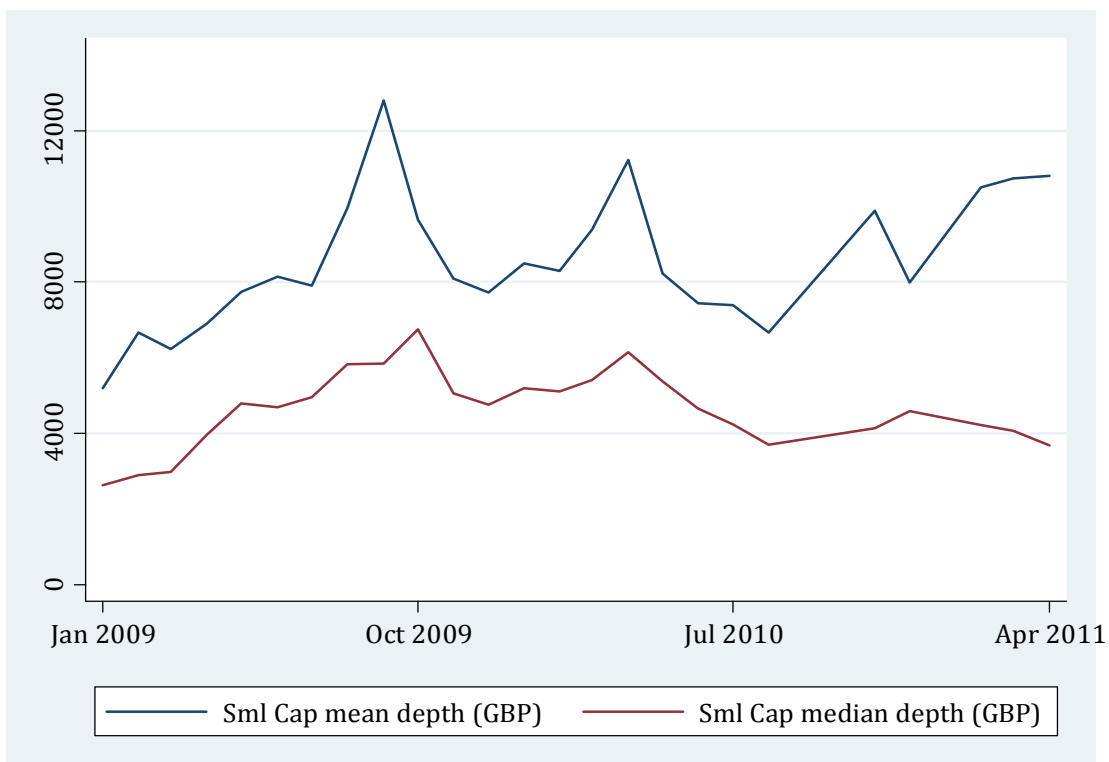


FIGURE 11: LSE ORDER BOOK DEPTH AVAILABLE AT THE BEST QUOTES,
(GBP) FTSE SMALL CAP STOCKS, 2009- 2011



Thus, we might tentatively conclude that it is HFT causing the changes in liquidity we observe in large caps. However, none of this can be construed as concluding evidence, and more research is needed. In particular, the relatively mediocre state of liquidity in Small Caps could be an indirect effect of the growth in CBT – a ‘negative externality’. We explore this hypothesis in the next Section.

Order flow redistribution across stock classes

The evidence on trade size patterns above suggests that CBT is focussed on large caps. In such assets, costs are smaller, counterparties more frequent and volumes are larger. Did CBT redistribute trading interest and volume away from small and mid-cap securities and towards large caps? This might cause large-cap spreads to narrow further and thus draw non-CBT trading interest away from smaller stocks.

The Economist (2009) argues that this is precisely what occurred: *“The ‘high-frequency’ traders who have come to dominate stock markets with their computer-driven strategies pay less attention to small firms, preferring to jump in and out of larger, more liquid shares. Institutional investors, wary of being stuck in an illiquid part of the market, are increasingly following them.”* (“High-Speed Slide”, *The Economist*, 12 Nov 2009).

In this scenario, the growth in CBT could have negative implications for the liquidity and pricing efficiency of the shares of small firms. As a result, hundreds of smaller companies, whether listed on the Official List or on AIM, could suffer deterioration to their cost of equity capital.

Trading activity and investor interest

To supply tentative evidence, we computed the proportion of total activity by value that has taken place in large, mid and small cap firms since 2001 and across all trading venues. The results are depicted in Figure 12 below (where the three bars add up to 100% for each year):

FIGURE 12: PERCENTAGE OF TOTAL VALUE TRADED BY STOCK SIZE CLASS:

2001 TO 2011/Q1

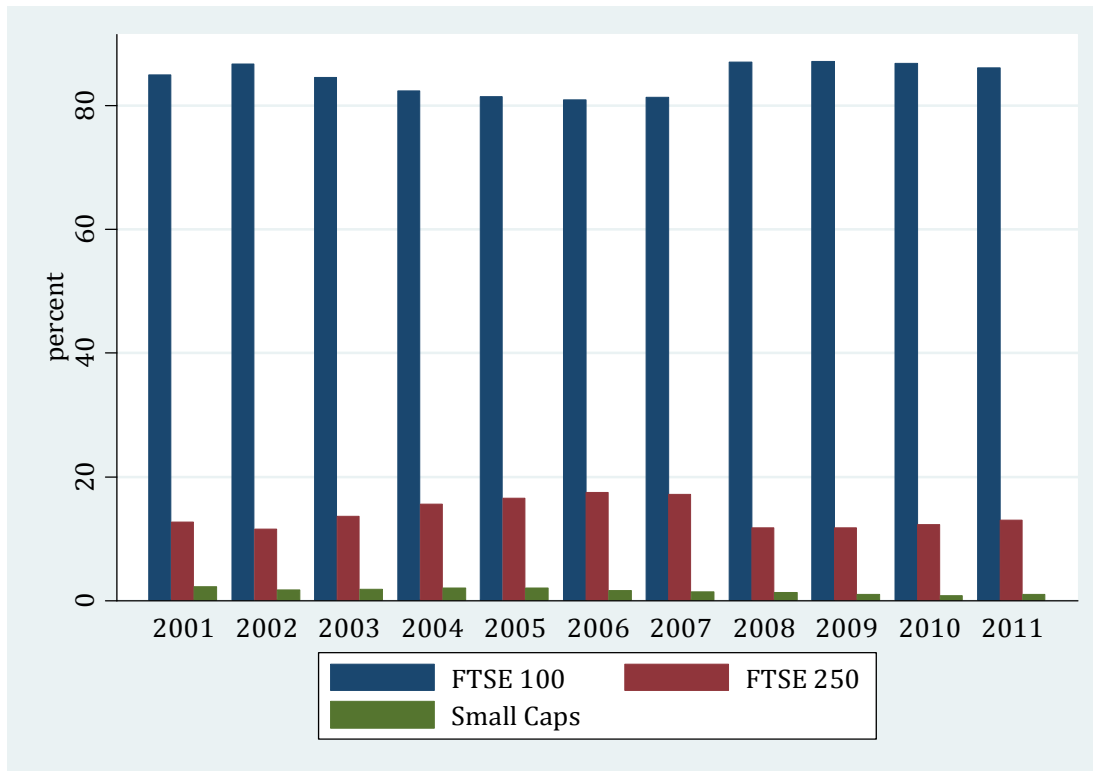


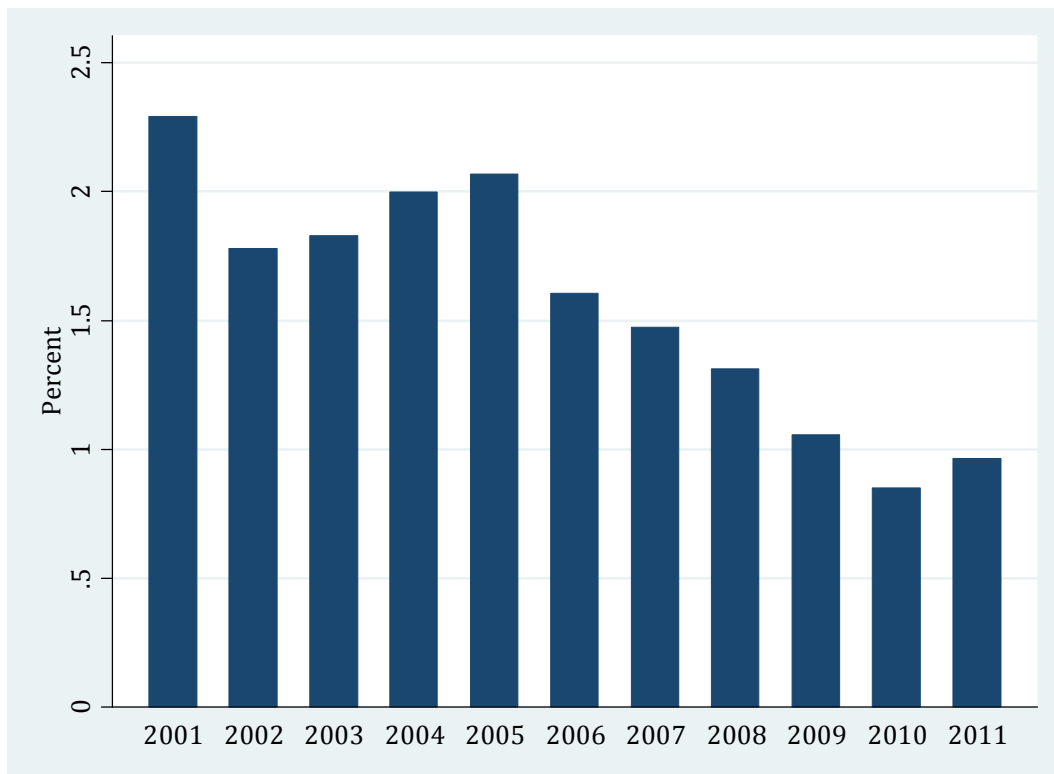
Figure 12 shows that trading interest across the three classes of equities by size is roughly proportional to their respective market capitalisations. The firms making up the FTSE 100, 250 and Small Cap indices currently represent respectively about 81%, 15% and 2% of the total capitalisation of the London Daily Official List of quoted companies (with the remainder taken by FTSE Fledgling firms).¹³

On Figure 12, the main substitution effect seems to occur between the FTSE 100 and the FTSE 250 index components, and it seems clearly disconnected from growth in CBT but could instead be related to broad market movements, investor risk aversion or shift in industrial makeup (e.g. the development of high growth industry sectors causing firms in these sectors to appear in indices below the FTSE 100).

To make trends in Small Cap index components clearer, Figure 13 shows the proportion of turnover received by Small Caps only. From 2001 till 2005 included, it hovered around 2% but afterwards experienced a decline that brought it down to less than 1%. This decline coincides with the reduction in trade size from 2006 that we identified above and that we related to the growth in CBT.

¹³ In turn, market values within the FTSE 100 index itself are extremely skewed by a few very large companies: the top ten stocks represent nearly 50% of the index value.

FIGURE 13: PERCENTAGE OF TOTAL VALUE TRADED IN FTSE SMALL CAP STOCKS:
2001 TO 2011/Q1



This pattern suggests that the development of computer-driven trading may have reduced the trading attention received by small caps. The new trading techniques may have focussed activity on larger issues, though it's clear that this segment of the market was already marginal in terms of total order flow.

- A caveat that is in order here is that the number of companies that the Small Cap segment comprises has been steadily declining over the past decade: there were about 400 stocks in the index at the start of 2001 and about 270 of them ten years later. We lack the detailed data that would allow us to correct for this bias. We doubt though that it would affect the observed decline since 2006 significantly, as the number of component stocks was already down to 330 by then. It's likely that the 60 companies that the index lost between 2006 and 2011 were among the smallest but we lack the data to verify this.

Other evidence of investor and analyst interest in smaller issues might provide a useful complement to these basic results.

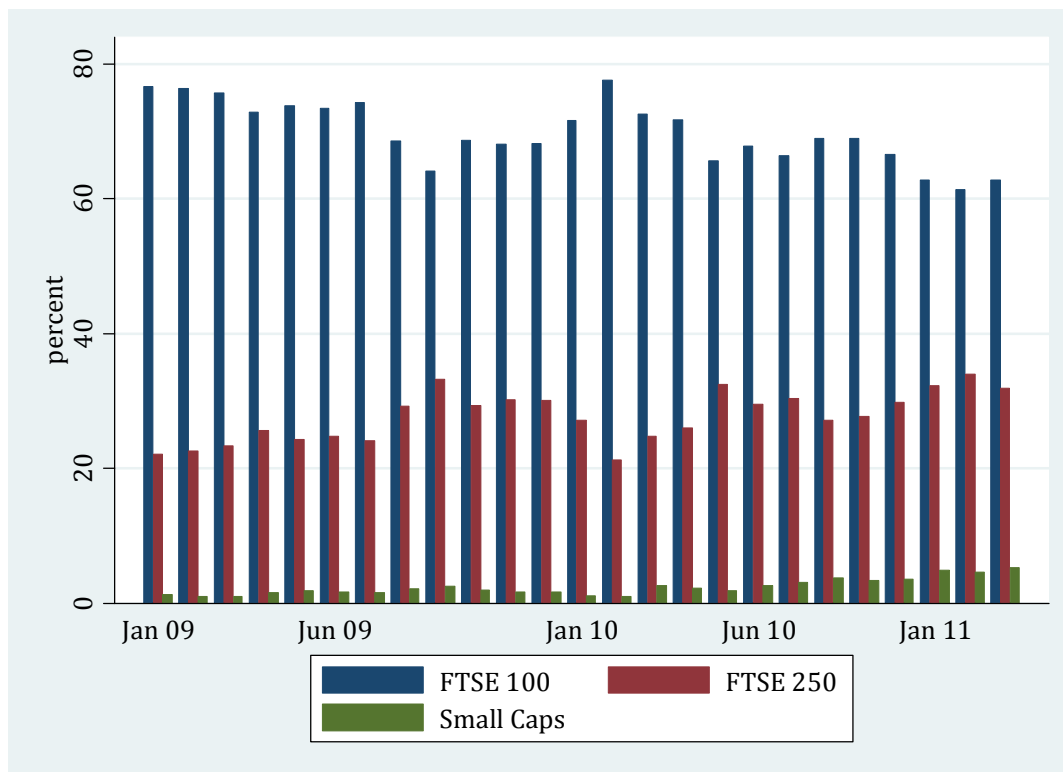
Quoting activity

Turning to quoting activity using high-frequency data since the start of 2009, Figure 14 shows that perhaps surprisingly, large caps appear to represent today a smaller proportion of all quotes than they do of trades or market values. The Figure shows that the proportion of quote revisions that large caps make up is only slightly above 60% while that of mid caps has been inching

towards 30% over the last two years. This suggests that HF market-making has gradually extended to mid-cap stocks.

- A caveat is that these pictures show quote updates on the LSE's order book only. We have not got detailed enough data on the order books to construct consolidated graphs. Since very little quoting and trading in small caps takes place on non-LSE order books, our pictures below must understate the proportion of quote revisions that takes place in large and mid-caps today (even if a proportion of the quote updates sent by firms to different venues could be perfect duplicates).

FIGURE 14: PROPORTION OF MONTHLY QUOTE UPDATES
IN LARGE, MID AND SMALL CAPS, LSE ORDER BOOK, 2009-2011.



Therefore, Figures 8 to 14 do not raise concerns that an HFT-induced drought in liquidity is affecting mid caps, but the situation regarding smaller issues is less clear. The comparatively mediocre state of liquidity in Small Caps could be interpreted in three ways:

- Since 2009, larger companies have received the liquidity benefits of the growth in High-Frequency trading, of which smaller issues have been left out.
- Negative externality: liquidity in small caps has suffered from the growth of HFT in larger issues.
- Uncertainty and investor risk aversion towards large and mid-caps have abated in the post-crisis environment but they have remained stubbornly high for the stocks of less liquid companies, which are considered most vulnerable to a protracted period of weak growth.

Explanation 1 would become less plausible if our previous evidence that HFT has not seen much growth since 2009 was confirmed. We return to this issue in the next Section.

Is CBT still growing?

We have reported evidence consistent with a recent levelling off of CBT. The specialised financial press has mentioned indirect evidence having same flavour.

- The *Financial Times* recently reported that “Larry Tabb, chief executive of Tabb Group, a consultancy, said high-frequency trading now accounted for 54 per cent of overall US equity trading, down from an earlier Tabb estimate of 61 per cent in 2009. The level in Europe fell from 38 per cent last year to 35 per cent, although Tabb is expecting a small uptick towards the end of the year.”¹⁴
- Similarly, the *Financial News* has reported evidence that the profitability of some major HFT players is declining.¹⁵ The article notes that “the firms that conduct [HFT] are almost entirely dependent on trading revenues, and they need both volume and volatility to profit from this activity, both of which have fallen away”. According to this view, the high rates of HFT growth observed in earlier years could be the result of exceptional market conditions.
- The development of “multi-asset” trading platforms was described to us in interviews as the current major development on the part of both traders and exchanges. Similar evidence has appeared since 2010 in the specialised press. The *Financial Times* recently noted that “High frequency traders are (...) turning their attention to developing strategies and computer algorithms that can carry out ultra-sophisticated arbitrage between asset classes, rather than darting in and out of markets as fast as possible.” (“Super-fast traders feel heat from competition”, *Financial Times*, 14 April 2011) This is consistent with the view that HFT activity has come closer to saturation in equity markets, given recent trading demands and market conditions.

Therefore there seems to be suggestion on various fronts that CBT may be stalling or receding somewhat in equities and that the marginal profitability of HFT strategies is declining.

We now turn to discussion of some of the risks that CBT may cause or increase.

¹⁴ “High-frequency boom time hits slowdown”, *Financial Times*, 12 April 2011.

¹⁵ “Is the party ending for High-Frequency traders?”, Tim Cave, *Financial News*, 18 Oct 2010.

Risks generated by CBT and areas for further research

We see risks from CBT as possibly arising from several areas, from market quality and the possibility of market dislocation to the manner in which CBT may redistribute wealth among market participants, and the implications this may have for market structure.

Volatility, price and liquidity crashes

- CBT is directly linked to *liquidity crashes* caused by market-making algorithms withdrawing from liquidity supply at the same time (Easley, Lopez de Prado and O'Hara 2011).
- There is also a concern of *heightened intraday volatility*, not related to uncertainty. It can be partly caused by feedback between algorithmic scripts, of the type described in O'Hara (2010). For example, order book imbalance, intra-day momentum and order flow-based trading rules will tend to trade towards the less liquid side of a book. This tends to cause price spikes and feed-back to generate further signals from those rules. Latza and Payne (2011) show how one particular algorithmic rule that uses order book imbalances can help reduce execution costs and speculate that its use might exacerbate flash crash type behaviour. Anecdotal evidence of 'mini' flash crashes in various classes of assets since the May 2010 event in the US have appeared in the financial press and in practitioner reports on a regular basis.
- As HFT develops across asset classes, there is also a risk that it will increase correlations in volatility and liquidity supply and demand across equities, currencies, commodities and futures. This may lead to correlated liquidity spikes and troughs across classes.

CBT, winners and losers, and market structure

Our key concern is that CBT is causing wealth to be redistributed across the trading landscape, possibly to the benefit of proprietary, predatory CBT firms and away from end investors (i.e. those invested in pensions or mutual funds). This should be an area of significant concern for policy makers, as it may affect the performance of the investment and retirement savings of British households. Figure C in the Appendix to this document shows how the assets managed by the mutual fund industry have grown over recent decades as a proportion of GDP.

The dominance of CBT on the agency side seems to have led to a diminished role for the traditional equity dealership model. Comparison of equity and FX markets makes this clear. This may induce banks to devote less capital to dealing services, thus making the execution of non-standard trades more expensive relative to the subset of trades that are most amenable to algorithmic execution.

- Risk: is the (presumed) profitability of predatory, proprietary algorithmic trading coming at the expense of end investors in investment and pension funds? If so, it is difficult to see the economic value of such CBT. (In the estimations above, we observed positive trends in large cap liquidity but we only captured two very simple dimensions of liquidity. Other measures such as total displayed and hidden depth, and dynamic price impact are more relevant to institutional traders.)

On the other hand, one could argue that if proprietary CBT is exploiting poor algorithm design on the part of agency CBT, then they deserve their profits. The agents who should be

pressured to change are those designing algorithms for executing agency flow. The incentives of agency firms may be less strong than those of prop outfits.

Again, prop, market-making algorithms may simply be exploiting a lack of competition that may have existed in dealer liquidity supply. If they can intermediate more efficiently and undercut traditional dealers and still make money, then they and ultimate investors could both be better off.

CBT and liquidity supply: market depth

Intuition suggests that the 'continuous' order flow that CBT generates involves smaller quoted sizes that cause deterioration of the ability to trade in large sizes, such as market depth and trading immediacy. Brogaard (2010) reports evidence consistent with HF traders contributing little to market depth.

CBT and liquidity supply: continuous market presence

Are prop CBT firms just intelligent market makers or are they aggressive and predatory? Much opinion and discussion seems to be based on the latter view when little is known as to whether this matches reality. One might argue, given the evidence on spreads and depth above, that much HFT activity may well be market-making and thus trading passively.

- Risk: even if they are intelligent market makers, CBT firms are under no obligations to stay in the market. If trading conditions caused CBT firms to withdraw from making markets, who would contribute to price formation and liquidity in a market structure that had become very reliant on them?

CBT and the role and incentives of exchanges and MTFs

The incentives of exchanges and MTFs must also be considered. As companies their goal is to maximise shareholder wealth through the design and pricing of their trading systems. How have exchanges responded to the growth of CBT and how might they respond in future?

- Exchanges are themselves profit maximisers. They generate revenue through trading and listing fees.
- Trading fees are largely volume and order based. Thus exchanges have an incentive to attract high volume traders i.e. those doing high-frequency, computer based trading. (As an example, they are charging for co-location services to host the IT infrastructure of HF traders.)
 - Risk: if exchanges are skewing the playing field towards HF traders, how are outcomes for other traders being affected?
 - Risk: are exchanges making it easier for CBT firms to profit at the expense of those executing in more traditional fashion?
 - Risk: what are the implications of this for pricing efficiency, volatility and market depth?

CBT and fragmentation

Order flow is fragmented when it is executed on several venues. A trade-off occurs between the potential benefits of increased competition between venues, spurring reductions in fees and technological innovation, and the fact that the same trading interest is spread across venues, potentially giving rise to less deep order books and less tight spreads other things equal.

Schwartz (2010) argues that the current trading environments combine the disadvantages of spatial and *temporal* fragmentation of liquidity (the latter caused by the thin, continuous order flow that HF trading generates, the opposite of batch trading).

Increased fragmentation of liquidity has been largely concomitant with the increase in HF trading in mature markets. Figures 15A and B below depicts these trends for FTSE 100 and 250 stocks, respectively:

FIGURE 15A: LSE, CHI-X, BATS AND TURQUOISE MARKET SHARES BY VALUE TRADED, FTSE 100 STOCKS, 2007-APRIL 2011

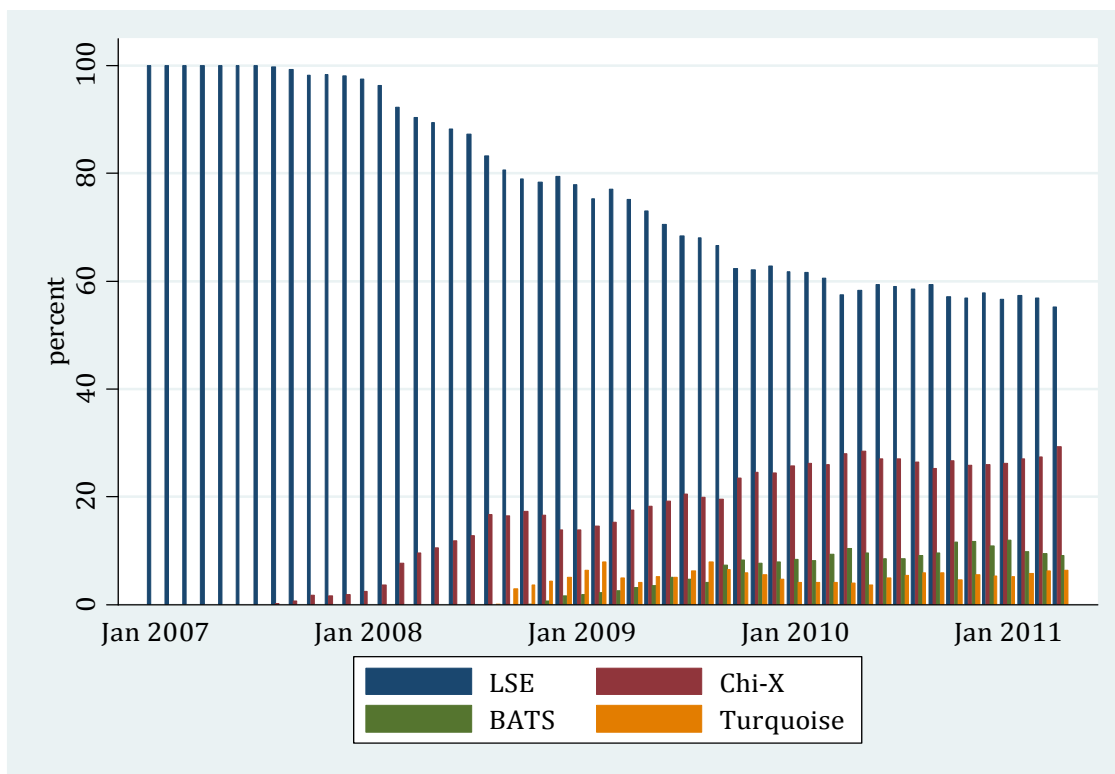
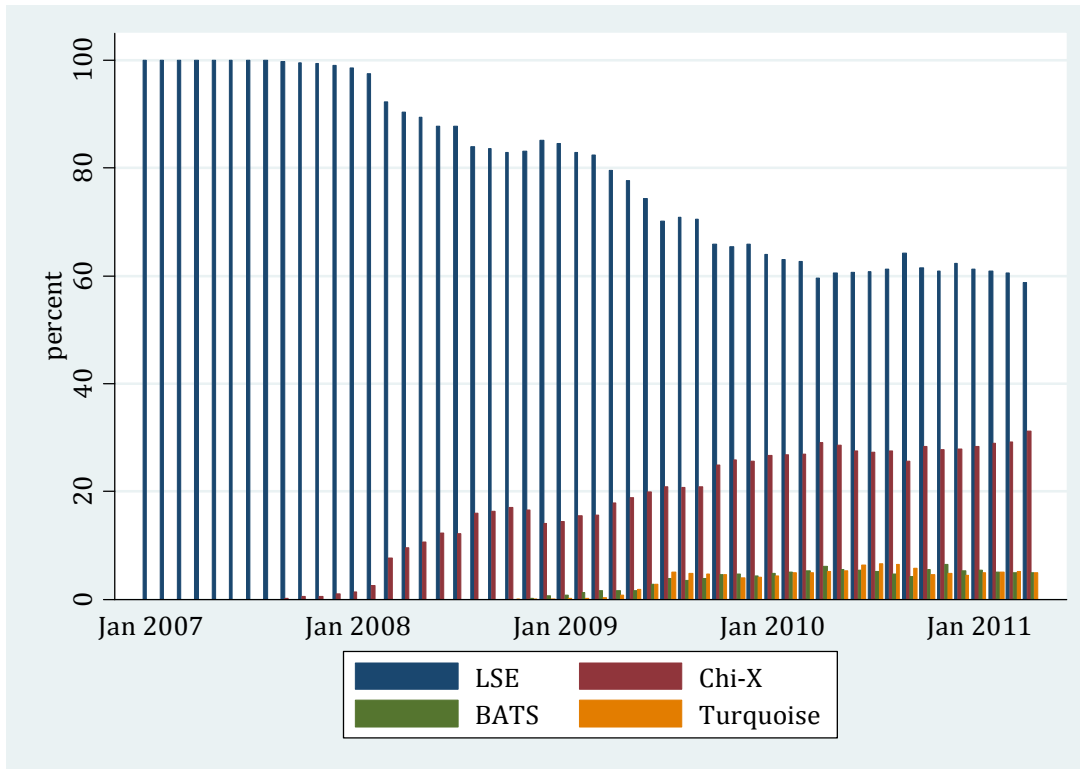


FIGURE 15B: LSE, CHI-X, BATS AND TURQUOISE MARKET SHARES BY VALUE TRADED, FTSE 250 STOCKS, 2007-APRIL 2011



Fragmentation seems to have increased monotonically until late 2009 but the LSE's market share has remained stable since (and the market share held by its largest competitor Chi-X has kept increasing at the expense of smaller venues).

Comparing the Figures also reveals that levels and trends in fragmentation are remarkably similar for large and mid-caps. The London Exchange's market share started falling round the same time and stands at about 60% for both indices, in spite of the very different levels of activity and liquidity that their component stocks exhibit. This is surprising to us.

In general terms, the Figures have similar flavour to Figures 5, 6 and 7 depicting trade sizes, in the sense that fragmentation seems undisturbed by market movements, volatility, risk aversion or other factors that have strongly affected trading activity itself.

A clear difference though is that the decrease in trade size we related earlier to the development of CBT as has been very stable since the start of 2009, whilst *fragmentation has kept increasing over that year*. This suggests that there isn't a 'mechanical' relationship between computer-based trading and fragmentation.

Is HFT a cause of, or a remedy to fragmentation? Here again, little is known of the interplay between fragmentation and algorithmic trading and its consequences on liquidity:

- Algorithmic trading development could be partly *caused* by fragmentation: post-Mifid, new trading venues (e.g. BATS) appeared with the stated aim of attracting HF flow (emphasising low latency and designing their fee structure accordingly). Other venues had to follow suit or lose this type of flow.

- Fragmentation has led to the development of HF trading strategies *that profit from it* by exploiting price and liquidity discrepancies across venues -- take liquidity that's in one venue for non-informational but random order arrival reasons and resell it in another venue at a small profit.

Concluding comments

We have reported evidence consistent with Computer-Based Trading having greatly altered the trading landscape in UK equities over the past decade. Of course, this must come with the proviso that, without direct measures of CBT, we cannot definitely link CBT to trends in market activity and liquidity.

We find evidence consistent with CBT generating order flow that is more 'continuous', with smaller trade sizes, more frequent trades. We are only beginning to understand the time-series properties of this flow and its relation to liquidity and volatility.

Our preliminary evidence also suggests that trends in trade sizes have levelled off, and that the increase in CBT that has affected larger stocks may have diminished trading interest in the stocks of hundreds of smaller listed companies, with attendant negative impact on liquidity.

Much more analysis is needed to confirm these basic results, as well as to understand what factors may shift CBT away from its current levels and whether these levels, thus far entirely determined by market forces, can be considered optimal.

In this context, the decision to impose a securities transactions tax that is currently mooted by some European constituencies would be very likely to hinder the participation of computer-driven traders -- particularly since the tax would bear on *total trade value* while the profitability of HF trading depends on small *capital gains* averaged over a large number of trades. Based on our current understanding of the roles that these traders play, the effects that such a tax would have on market liquidity are impossible to determine and they could be deleterious.

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Appendix

Figure A: FTSE 100 index movements since 2006 (dividend income reinvested)

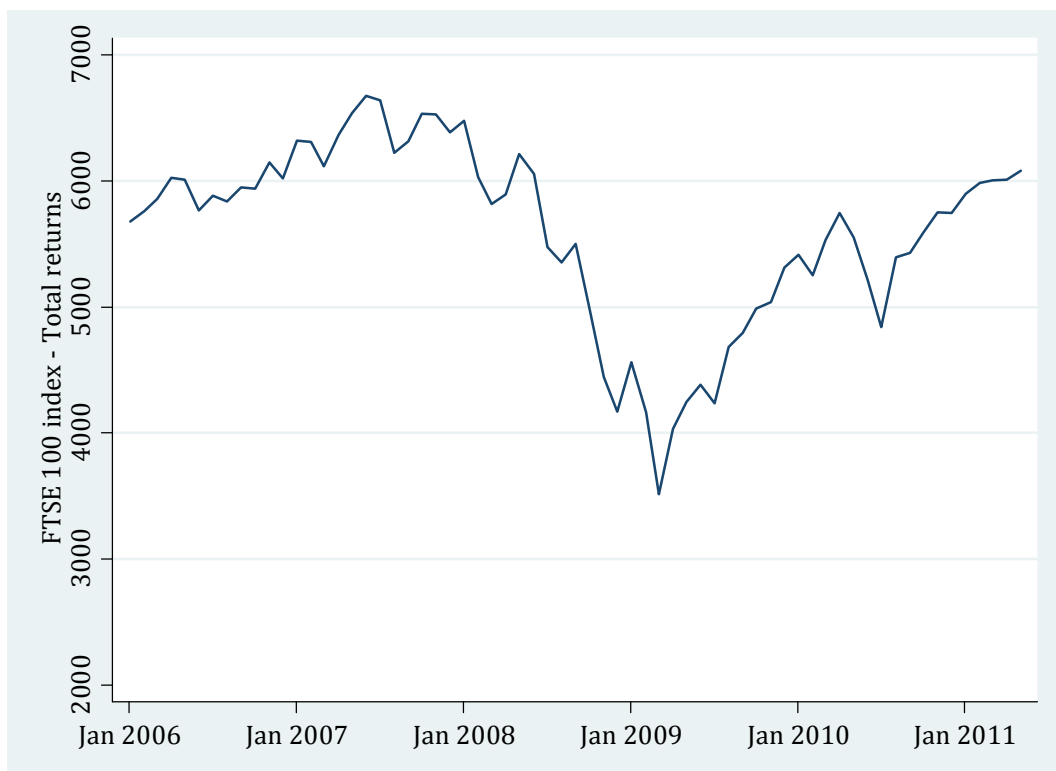


Figure B: VFTSE index movements since 2006. This index is a measure of expectations of volatility derived from option prices. It is the UK equivalent of the VIX index, sometimes dubbed the “Fear Index”, used for the US market.

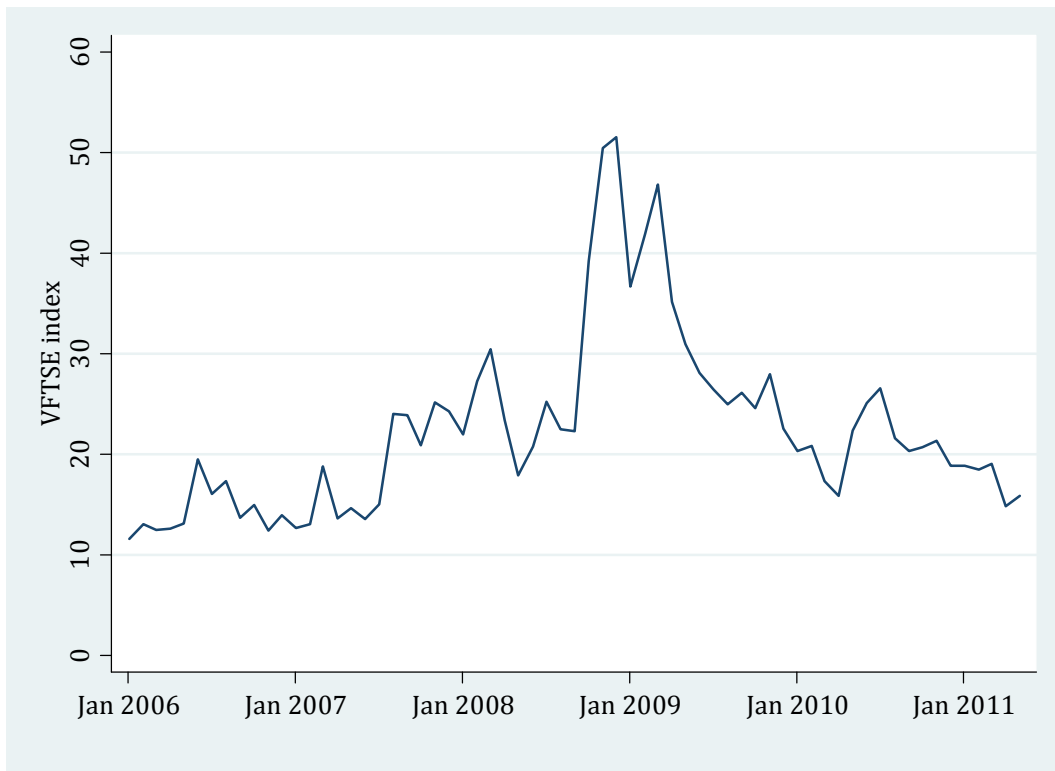


Figure C: Assets under Management in the mutual fund sector, expressed as a proportion of UK GDP (From Investment Management Association, “Asset Management in the UK 2009-2010 Report”).

Chart 29: Industry funds under management as percentage of GDP (1960 - 2009)

