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The impact of Intermarket Sweep Orders on volatility: an agent-based stock market model

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Abstract

For some time, Intermarket Sweep Orders have been at the center of debate about their alleged harmful impact on orderly functioning of financial markets. This paper contributes to the research by describing the implementation of an Agent-Based Model to simulate the behavior of two markets with the aim to study price movements in presence of such orders. As needed in all simulations, care has been applied to represent all different possibilities and behaviors of agents. On the one side, the findings confirm acceleration of volatility when Intermarket Sweep Orders are executed in quiet markets. Under the exception provided by current regulation, markets may be subject to unexpected turmoil due to trade-through. Indeed, several authors highlight the potential danger for financial stability. On the other side, preliminary results of the simulation suggest that, under exogenous stressed conditions, Intermarket Sweep Orders do not constitute an exacerbating factor and, at the contrary, they may even slightly contribute to re-establish a controlled environment.

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1. INTRODUCTION

Regulation of National Market System (Reg NMS) Rule 611 states that a trading center must re-route orders to another trading center if the latter displays a better price for filling such orders. Violations of the rule are sanctioned. Yet, given that modern trading is heavily influenced by execution speed, the Securities and Exchange Commission (SEC) provided an exception to the rule, allowing Intermarket Sweep Orders (ISO). These are marketable limit orders that get immediately executed in the chosen trading center (otherwise they are canceled) regardless to the price, providing other orders are being contemporaneously submitted to all trading centers posting better prices at the top-of-book. In times of sub-second trading, prices displayed by a market center could vary faster than updates can be communicated between trading centers. Traders seeking execution at a fixed price often cannot afford the (time-consuming) luxury to delegate to the NMS decisions about which market to execute their order in. ISOs are used extensively for executing orders at specified prices, albeit potentially worse than the National Best Bid or Offer (NBBO) and also for splitting large orders and so concealing trader's intentions. Several researches recognize usage of large percentages of ISO over total traffic, making the former one of the principal actors of the digital trading pit. Because of their search for speed, ISOs are natural weapons of High-Frequency Trading (HFT). Aggressiveness demonstrated by willingness to trade, even at inferior prices, attracted onto such orders suspects of being the culprit of violent volatility events and even of flash crashes, although research seems to be inconclusive about their role. ISOs are considered to handle smaller volumes per trade than non-ISOs (NISO), to show higher imbalances and higher autocorrelation (Nguyen et al., 2019). These characteristics contribute to cast shadows over the impact ISOs have on markets, especially when they are already under stress. Since summer 2007, when Reg NMS Rule 611 and ISO exceptions entered into force, criticisms piled up and over time several academics, experts and practitioners suggested total ban of ISO (Golub et al., 2012) or at least severe limitations to its use (McInish et al., 2014).

In the following, section 2 revises the literature, section 3 describes the methodology used, section 4 discusses the results and section 5 concludes.

2. LITERATURE REVIEW

ISOs offer the benefit of faster execution with respect to non-ISOs; for this reason, aggressive traders make extensive use of them. Chakravarty et al. (2012), observing 120 stocks on NYSE and NASDAQ, find 46% of all trades being ISOs, for a quota of 41% of total volume traded over the sampling period August 20, 2007 through May 30, 2008. Other studies, analyzing different samples, find different but essentially consistent usage. According to Cox (2021) ISOs represent nearly 48% of NYSE trading between January 2015 and September 2016 whereas for Nguyen et al. (2014) they account for 38% of trades, albeit only 31% of volume in a September 2007-December 2013 sample. The difference between number of trades and volume traded seems to match the common habit of speed-seeking traders (as ISO traders are) to deal in smaller lots than traditional operators and MacKenzie (2014, p.43) even suggests their use being "crucial to the successful practice of HFT". A study by Budish et al. (2014) notices how trading time dropped from an order of magnitude of hundredths of second down to milliseconds and then tenths of millisecond, just over the decade 2005-2014. Because of their closeness to search for speed and fast trading, ISOs have naturally been associated to extreme events occurring at high speed, like the infamous flash crashes. Indeed, McInish et al. (2014, p.508) find a "disproportionate impact on market conditions during the Flash Crash" by ISO use. Actually, there are many hypotheses about the causes of the May 2010 Flash Crash but despite some authoritative academic studies, the CFTC-SEC Final Report (CFTC-SEC, 2010) does not mention ISOs among the possible causes of the event. Yet, some authors go as far as to hypothesize a definitive causal relationship between ISOs and crashes. McInish et al. (2014)

find ISO volume on that day significantly higher than on other days and identify it as a major source of what Easley, Lopez de Prado and O'Hara (2011) call 'market toxicity'. According to Cox (2021) there exist evidence suggesting extreme price pressure caused by substantial volume of ISO-led order splitting and trading aggressiveness. Golub et al. (2012) observe the impact of ISOs over the dramatic price drop of the vast majority of stocks and albeit results are not definitive, they suggest that ISOs may destabilize markets. Although Shearer (2020) is more cautious in identifying ISOs as the cause of the Crash, it also recognizes that trade-throughs could exacerbate price volatility. On their side, Braun et al. (2018) find a number of cases in which ISOs initiated extreme events and suggest that small market orders may create them, whereas Cox (2021) labels ISO order imbalance as just 'informative' of future returns. Suggestions pile up and Golub et al. (2012, p.7) claim that "the overwhelming majority of crashes is due to aggressive use of ISOs" and that "[t]his is an evidence on excessive use of ISOs". These statements can be considered declarations of a direct causal relationship from ISOs to flash crashes. Equally bold is Madhavan (2012, p.22) who states causation between "rapid growth of high-frequency trading and use of aggressive sweep orders in a highly fragmented market". According to McInish et al. (2014) ISOs 'drive' returns whereas for Shearer (2020) ISOs only can 'aggravate' crashes, without generating them but somehow exacerbating volatility.

3. METHODOLOGY

This paper presents an Agent-Based Model (ABM) that simulates two real markets starting off with the same prices and then progressing independently from each other. Occasionally top-of-book prices in different venues diverge and when that happens, Market orders are being rerouted to the venue displaying a better price, unless they are marked as ISO. This scenario would allow to replicate the behavior of real-life trading in presence of trade-through exceptions. The ABM works as follows.

1) This experiment is made up of 10,000 operations for each cycle and it launches 100 independent cycles in order to generate sufficient data for statistical purposes. For each operation, the simulation first randomly selects the market on which to operate.

2) Then, it randomly selects the Book (Bid or Ask) it will operate onto. Next, it randomly decides the order type (Limit or Market) and the type of trader: HF (High-Frequency) or LF (Low-Frequency) trader. The large majority of traders belongs to the latter category but fast traders operate much more frequently. In case of Market Orders, the algorithm randomly selects ISO or NISO. All selections above are parameterized and the complete process is launched for each possible combination of ISO percentage (0% to 90%, with 10% steps) and HFT (same range and steps) over total orders.

3) Without loss of generality, each operation is supposed to last one time-unit. Whereas orders posted by HF traders are executed immediately, LF orders, whether Limit or Market, suffer a latency and their execution is delayed by 350 time units that, in the simulation, represent a few hundreds of milliseconds' delay. ISOs are executed on the selected market whereas for NISOs the simulation first checks which market displays the best price and then executes the order on that market.

Each individual operation is being logged and after each cycle the log is analyzed in order to compute mean and standard deviation of Minimum Price, Maximum Price, Global Volatility (Max price – Min price) and Local Volatility. Local Volatility represents the number of individual price changes over the total number of trades executed and provides information of profit/loss opportunities for each operation (that is, at sub-second level). The last step of analysis computes t-statistics about Global and Local Volatility for each simulation comparing the values in correspondence of ISO>0 with respect to ISO=0 and the comparison of both types

of volatility. The same computation is replicated for all percentages of HFT over total trading. The result of this ABM is reported in table 1 panel A.
The previous process describes a quiet market (BASE mode), that is, a market working under relatively quiet conditions, which the simulation mimics with random choice between Limit or Market orders. To the purpose of verifying the behavior under stressed conditions, the entire process has been run again under the TREND mode, obtained by increasing the parameter selecting the percentage of Market Orders over the total number of orders. This way, there are more aggressive orders and therefore more trades with respect to quotes. The result is a market with higher volatility, as depicted in table 1 panel B.
The simulation has been developed in VisualBasic and Microsoft Excel. This choice presents the advantage of source code and data base within the same file. The code is relatively simple and less than 5,000 lines long. Further details are available upon request.

4. DISCUSSION

4.1. Why Using a Simulation?

A simulation is, under any respect, an experiment although the behavior of all agents is being artificially programmed. Nevertheless, this simulation describes different types of behavior in order to represent a wide range of agents (Maslov, 2000 and Reiss, 2011). In economics and finance ‘real’ experiments are rare as in most cases it is impossible to instruct economic agents to behave as expected by the researchers. That is why they use simulations (and ABM in particular); this way it is possible to create the required environment and study its outcome. Moreover, with simulations it is possible to generate environments that cannot be observed in real life. This happens for the extreme cases of 0% or 90% ISOs as well as 70% through 90% HFT over total trading, since all these conditions do not normally occur in real markets.

Panel A: BASE case		ISO=0	ISO=10	ISO=20	ISO=30	ISO=40	ISO=50	ISO=60	ISO=70	ISO=80	ISO=90
HFT=0	Delta Price	0.028	0.032	0.037***	0.039***	0.036***	0.039***	0.037***	0.038***	0.035***	0.034**
	Local Volatility	0.481	0.481	0.481	0.481	0.481	0.486	0.487*	0.491***	0.495***	0.499***
HFT=10	Delta Price	0.017	0.024***	0.027***	0.030***	0.028***	0.030***	0.031***	0.032***	0.032***	0.036***
	Local Volatility	0.500	0.501	0.502	0.504	0.505*	0.505*	0.505	0.508**	0.506*	0.510***
HFT=20	Delta Price	0.021	0.027***	0.032***	0.031***	0.031***	0.033***	0.036***	0.036***	0.040***	0.044***
	Local Volatility	0.500	0.500	0.502	0.505*	0.509***	0.509***	0.51***	0.512***	0.514***	0.515***
HFT=30	Delta Price	0.028	0.032*	0.031	0.033**	0.035***	0.038***	0.041***	0.041***	0.046***	0.057***
	Local Volatility	0.494	0.498	0.501**	0.503***	0.507***	0.509***	0.512***	0.515***	0.520***	0.525***
HFT=40	Delta Price	0.027	0.033	0.034	0.033	0.035	0.036	0.038	0.042	0.047	0.057
	Local Volatility	0.495	0.499	0.499	0.504***	0.507***	0.510***	0.512***	0.516***	0.518***	0.524***
HFT=50	Delta Price	0.035	0.037	0.037	0.039	0.041**	0.042**	0.044***	0.047***	0.052***	0.06***
	Local Volatility	0.486	0.491	0.494**	0.497***	0.500***	0.505***	0.509***	0.512***	0.517***	0.522***
HFT=60	Delta Price	0.039	0.039	0.040	0.044	0.042	0.047***	0.046**	0.047***	0.050***	0.054***
	Local Volatility	0.478	0.480	0.483	0.487**	0.489***	0.494***	0.498***	0.504***	0.509***	0.510***
HFT=70	Delta Price	0.035	0.038	0.040*	0.042***	0.044***	0.047***	0.044***	0.048***	0.049***	0.057***
	Local Volatility	0.478	0.479	0.486**	0.487**	0.490***	0.495***	0.498***	0.502***	0.507***	0.512***
HFT=80	Delta Price	0.033	0.040**	0.041***	0.042***	0.042***	0.046***	0.043***	0.046***	0.047***	0.047***

	Local Volatility	0.479	0.477	0.479	0.483	0.484	0.490***	0.490***	0.496***	0.499***	0.503***
HFT=90	Delta Price	0.033	0.037	0.038	0.042	0.042	0.040	0.042	0.042	0.041	0.042
	Local Volatility	0.478	0.478	0.478	0.482	0.482	0.484*	0.488***	0.492***	0.497***	0.501***

Panel B: TREND case		ISO=0	ISO=10	ISO=20	ISO=30	ISO=40	ISO=50	ISO=60	ISO=70	ISO=80	ISO=90
HFT=0	Delta Price	0.422	0.441*	0.435	0.447**	0.437	0.421	0.400	0.382	0.353	0.313
	Local Volatility	0.262	0.267	0.274***	0.277***	0.284***	0.289***	0.289***	0.292***	0.291***	0.292***
HFT=10	Delta Price	0.163	0.173*	0.179***	0.179***	0.189***	0.187***	0.196***	0.198***	0.214***	0.223***
	Local Volatility	0.447	0.458**	0.464***	0.469***	0.476***	0.479***	0.477***	0.473***	0.469***	0.461***
HFT=20	Delta Price	0.235	0.240	0.248*	0.249*	0.254***	0.270***	0.269***	0.278***	0.289***	0.307***
	Local Volatility	0.458	0.464	0.470**	0.473***	0.479***	0.477***	0.480***	0.477***	0.471***	0.464
HFT=30	Delta Price	0.584	0.590	0.577	0.585	0.590	0.584	0.573	0.575	0.579	0.589
	Local Volatility	0.424	0.432*	0.437***	0.438	0.444***	0.444***	0.446***	0.445***	0.444***	0.439***
HFT=40	Delta Price	0.580	0.573	0.589	0.581	0.583	0.584	0.579	0.588	0.577	0.586
	Local Volatility	0.428	0.435*	0.435*	0.439***	0.441***	0.442***	0.445***	0.441***	0.445***	0.439***
HFT=50	Delta Price	1.044	1.049	1.047	1.044	1.041	1.039	1.039	1.032	1.034	1.012
	Local Volatility	0.371	0.377	0.382***	0.387***	0.389***	0.389***	0.390***	0.390***	0.386***	0.386***
HFT=60	Delta Price	0.926	0.923	0.907	0.905	0.897	0.892	0.881	0.863	0.841	0.831
	Local Volatility	0.300	0.311***	0.317***	0.323***	0.328***	0.331***	0.334***	0.335***	0.335***	0.336***
HFT=70	Delta Price	0.913	0.925	0.915	0.910	0.894	0.890	0.877	0.865	0.848	0.827
	Local Volatility	0.303	0.311***	0.317***	0.323***	0.330***	0.330***	0.333***	0.334***	0.336***	0.336***
HFT=80	Delta Price	0.731	0.737	0.737	0.736	0.713	0.702	0.685	0.669	0.641	0.609
	Local Volatility	0.276	0.285***	0.293***	0.297***	0.304***	0.307***	0.312***	0.311***	0.313***	0.312***
HFT=90	Delta Price	0.589	0.593	0.593	0.581	0.573	0.566	0.544	0.517	0.481	0.460
	Local Volatility	0.265	0.274***	0.280***	0.286***	0.294***	0.296***	0.299***	0.301***	0.301***	0.300***

Table 1. Average of Delta price (Global Volatility) and Local Volatility for different combinations of ISO usage and HFT participation in respect to total market activity. Symbols *, **, and *** indicate significant difference with respect to ISO=0 at 1%, 0.1% and 0.01%, respectively

4.2. When a Result Is Significant

A simulation is a fictitious representation of the real world and it must be kept in mind that its results must always be taken with a grain of salt and a lot of skepticism. The same applies to experiments: before authorizing a drug for human use, it has to pass countless tests. It is far too easy to replicate experiments or simulation runs until an 'interesting' result is obtained and so claiming an extraordinary finding. Indeed, small input differences may lead to large differences in t-statistics. This is well explained by Spiegelhalter (2019, p.265): "One way around this problem is to demand a very low P-value at which significance is declared, and the simplest method, known as the Bonferroni correction, is to use a threshold of 0.05/n, where n is number of tests done". In this paper I used values of 0.01 (marked in the table with one asterisk, *), 0.001 (**) and 0.0001 (***). The last value is smaller than usual thresholds in hypothesis testing, even taking Bonferroni correction into account (with n=100, no. of cycles).

4.3. What the Simulation Tells Us – BASE Case

Table 1 panel A depicts volatility for different combinations of ISO usage and HFT under the BASE case, that is, in a relatively quiet market. The outcome confirms the worries of many researchers and practitioners: ISOs impact negatively on volatility. This can be observed in the line displaying results for 'Delta Price' (i.e. Global Volatility), where in general volatility augments as ISO usage increases. The results of all columns for which ISO>0 refer to the difference to the column ISO=0 and therefore display the volatility increase at that level of ISO usage compared to absence of ISO. For example, in the first row (HFT=0%), Delta Price is 0.028 in correspondence of ISO=0% and 0.032 for ISO = 10%. This difference is not significant at 1% whereas for ISO=20% Delta Price is 0.037, which is significant at 0.01%.
The row 'Local Volatility' reports the percentage of price change with respect to the last price traded. Large values of Local Volatility indicate flickering prices. Local Volatility also augments with ISO usage. Overall, it can be concluded that ISOs contribute to increase volatility both in the long-term (described by Global Volatility, that is, at daily horizon as well as hourly and in general at all psychological time horizons), as well as at sub-second level (as described by Local Volatility). This does not necessarily fingerpoint ISOs as the culprits of high volatility, crises or mini flash crashes; there is no causal relationship between data and events. Yet, this result confirms previous studies and recommends further research on ISO role in case of extreme events. Financial authorities and policy makers should take it into due consideration.

4.4. What the Simulation Tells Us – TREND Case

The results shown in table 1 panel B depict quite a different scenario. Local Volatility seems nearly always increasing with ISO usage, the only exception being the combination HFT=20% and ISO=90%. It is difficult to explain this anomaly even noticing that for ISO=90% Local Volatility often diminishes with respect to its level when ISO=80%. However, in some cases such diminution is not significant (e.g. 0.312 versus 0.313 at HFT=80% and 0.300 versus 0.301 at HFT=90%) and in any cases it can be explained by statistical oscillations possibly occurring in a simulation where several parameters depend on Random Number Generation processes. Nevertheless, in the TREND case as well, ISO usage seems to be correlated to an increase in Local Volatility. Totally different – and this is the most interesting result – is the analysis of Global Volatility (Delta Price). It represents the price change over the entire observation period. With few exceptions, mostly relegated to low levels of HFT activity (up to 20%), the difference in Global Volatility does not display any statistical significance between the cases of no ISO usage and ISO usage. In many cases the result is not even significant at 5% (not shown in the table) and sometimes Delta Price even diminishes as ISO usage increases. The non-significance is consistent across all levels of ISO usage for HFT>20%. This can be interpreted as ISOs' irrelevance when a market is already under stress due to exogenous reasons. That is, if volatility is already high, ISO do show any impact on it. Exogenous volatility overwhelms trade through and, at the contrary, the latter may even, at a certain extent, mitigate the former. One possible explanation of this preliminary result, and a guide for future causal investigation, is that liquidity consumption operated by ISOs tends to maintain prices within the intra-market spread and therefore it does not impact on Global Volatility. If markets behave erratically, as simulated in the TREND case, ISOs might be a stabilizing, rather than an exacerbating, factor. Another possibility is that the high speed of most transactions (that is, HFT>=30%) affects all markets in a way that surpasses the speed increase generated by ISOs. If all markets drop or spike rapidly, ISOs may act upon a price on a market whereas prices on other markets have already moved. All reasonable efforts have been made to prevent algorithmic details to inadvertently impact on the result of the simulation. More research is definitely required on this topic to confirm, or disprove, this anomalous result.

5. CONCLUSION

This paper presents a simulation of two markets that operate independently and varying percentages of HFT and ISOs execute therein (in both cases 0% through 90%, with 10% steps). It analyzes the impact of many different combinations of HFT and ISO usage. In fact, a simulation is able to inspect scenarios that are not easy, or even impossible, to observe in the real world. When markets behave quietly, the results confirm an accelerating impact of ISOs on volatility. This might lead to excess volatility, crises and even crashes, as suggested by previous research. However, under some specific conditions, the results of the simulation presented in this paper conflict with current interpretation of the impact ISOs have on the stability of financial markets. Indeed, when markets are already under stress, ISOs do not seem to affect price change and, in several of the cases studied, they even slightly reduce volatility. Should this (preliminary) result be confirmed by further research, it would rule out any role played by ISOs in the Flash Crash and other mini-crises occurred in recent years. A different story about ISO and crises should then be told, and different culprits sought. Erroneously identifying ISO as the cause of a crisis does not help to prevent future occurrences thereof. Moreover, this result could be an argument that Regulators might decide to take into consideration. That is the main contribution of this paper to existing literature. The result is counterintuitive and, if on the one side it calls for praising SEC's introduction of ISO exception to Reg NMS 611 (despite the many criticisms it attracted), on the other side it definitely calls for further research as required for either confirming or disproving this anomalous outcome. An interesting question arises about the causes of different outcome between BASE and TREND cases. Unfortunately, causal effect is a hard nut to crack in statistics (correlation is not causation): that's why I consider my results as preliminary and its causal explanation as a topic for further research.

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