Affecting Market Efficiency by Increasing Speed of Order Matching Systems on Financial Exchanges – Investigation using Agent Based Model

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Note: the opinions contained herein are solely those of the authors and do not necessarily reflect those of the affiliations.
(1) Introduction

(2) Artificial Market Model

(3) Simulation Results

(4) Summary & Future Works
The speed of order matching systems has been increasing due to
- Competition between Financial Exchanges
- Their investors’ demand

(Example of Speedup of an order matching system)

<table>
<thead>
<tr>
<th>Tokyo Stock Exchange’s Arrowhead (Started from 2010)</th>
<th>Latency (length of time required to transport data and match orders)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before Launch</td>
<td>3,000ms (3 seconds)</td>
</tr>
<tr>
<td>After Launch</td>
<td>4.5ms</td>
</tr>
</tbody>
</table>
Opposite Opinions in Increasing Speed

**Good Point**

Increasing market liquidity so that investors can trade without delay and large execution costs

**Bad Point**

Increasing maintenance costs of systems imposed to a Financial Exchange

What is the sufficient speed of Financial Exchange’s System?
• How much speed does a Market system need?
  - No Market system implemented further high-speed: Impossible to verify by using empirical study (historical data)

• If system’s speed effect market efficiency, what are the mechanisms?
  - Need to analyze Micro Process, but too many factors may affect stock’s price: Empirical study cannot isolate the pure contribution of speed

• Can investor buy or sell a stock around its fair (fundamental) price regardless of its speed?
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* Continuous Double Auction: as the real stock exchanges
* Simple Agent model: to avoid an arbitrary result

heterogeneous 1,000 agents
each agent places an order 10,000 times

**Expected Return**

\[ r_{e,j}^t = \frac{1}{\sum_i w_{i,j}} \left( w_{1,j} \log \frac{P_f}{P_t} + w_{2,j} r_{h,j}^t + u_j \epsilon_j^t \right) \]

- Fundamental
- Technical
- noise

**Order Process**

\[ P_{o,j}^t \sim N(P_{e,j}^t, P_\delta) \text{ where } P_{e,j}^t = P_t \exp(r_{e,j}^t) \]

\[ P_t > P_{o,j}^t \Rightarrow \text{Buy}, \quad P_t < P_{o,j}^t \Rightarrow \text{Sell} \]

**Replicate traditional Stylized Facts and Micro Structures**

Latency has Micro Structure Time Scale, Millie Seconds
How do we model it?

Latency
Time-lag required for data transfer and/or matching orders (The most important factor of Market’s speed)

Matching System
(Inside Financial Exchange)

Agents
(Investors)

New Order

Information of the order book (e.g. Updated Traded Price)

Match orders & Change price

We assume finite time intervals here = latency

An agent recognizes the price which is delayed for a latency
In most cases, an agent knows True Latest Price

\( \frac{\delta l}{\delta o} > 1 \) (slow)

True Price
(in Matching System)

Difference

Order & Price change

True and Observed prices are different

\( \frac{\delta l}{\delta o} \ll 1 \) (fast)

Order & Price change

Key Variables

Latency
constant = \( \delta l \)

Order interval = \( \delta t \)

exponential
random numbers

Avg. = \( \delta o \)
We can directly measure Market Inefficiency, by defining its Fundamental Price (=10,000) in Artificial Market Simulation. 

\[
\text{Market Inefficiency} = \frac{\text{Time Avg. of } |\text{Market Price} - \text{Fundamental Price}|}{\text{Fundamental Price}}
\]

The Market Inefficiency is based on difference between market and fundamental prices. If the price in the stock market highly deviates from its fundamental, the market was not considered to be efficient. 

→ But we don’t know the “true” fundamental price in real financial markets, so we can’t assess correct inefficiency by empirical studies.

Independent of time period used to calculate return.
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Inefficient

\[ \frac{\delta l}{\delta o} > 1: \text{Inefficient} \]

Right side \( \frac{\delta l}{\delta o} \geq 0.5, \) Market becomes Inefficient
\[ \delta l / \delta o > 1 : \text{Wider Bid Ask Spread} \]
\( \delta l / \delta o > 1 \): Increasing Execution Rate

Execution Rates (\(=\) Orders executed immediately / All orders)
Increasing Execution Rate especially near the Fundamental Price ($P^t \sim P_f$), where Technical term ($r_h^t$) dominates an expected return of an agent.
In a slow (δ₁/δ₀) market:

True Price > Observed: Positive expected returns, Upward trend expectation
True Price < Observed: Negative expected returns, Downward trend expectation

<table>
<thead>
<tr>
<th>δ₁/δ₀</th>
<th>Relationship between Observed and True prices</th>
<th>Execution Rate</th>
<th>Avg. Expected Return of agents</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>Buy Market</td>
</tr>
<tr>
<td>10</td>
<td>True P. &gt; Observed P.</td>
<td>32.5%</td>
<td>28.9%</td>
</tr>
<tr>
<td>(slow)</td>
<td>True P. &lt; Observed P.</td>
<td>32.5%</td>
<td>3.6%</td>
</tr>
<tr>
<td>0.001</td>
<td></td>
<td>31.2%</td>
<td>15.6%</td>
</tr>
<tr>
<td>(fast)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Population of data: all executions and orders
Agents then place unnecessary market orders. But, agents cannot quickly modify their expected prices. Observing price < True price ⇒ Market Buy order. Observing price > True price ⇒ Market Sell order.

A trend has actually been finished around Fundamental Price. But, agents cannot quickly modify their expected prices. Agents then place unnecessary market orders. Agents wouldn’t placed such orders if they knew the true price.
Mechanism of Large Latency ($\delta l/\delta o > 1$) making Market Inefficient

Stop Upward/Downward trend

But, agents cannot quickly change their expectation

Expanding Bid Ask Spread

Market becomes Inefficient

Large Latency

Unnecessary trend following orders

Especially near Fundamental Price

Increasing Execution Rate

Decreasing remaining orders near Market Price, relatively

Expanding Bid Ask Spread
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Summary

* The ratio \( \frac{\delta l}{\delta o} \) is key parameter, Latency \( \delta l \) per Average of Order interval \( \delta o \).

* the sufficient speed of Exchange’s System is \( \delta l < \delta o (\delta t) \).

* Trend stops in slow market (with Large Latency)
  -> agents cannot change Estimate price, quickly
  -> Unnecessary market following trades near fundamental
  -> Increasing Execution Rate -> Expanding Bid Ask Spread
  -> Market becomes Inefficient

Future Works

* We should discuss it with more kinds of agents and situations. (example: High Frequency Trading Agents, Crowded Orders immediately after great market impacting information)
Appendix
## Definition of Market/Limit order

In this study, there is a little difference from the actual market limit order. All agents decide an order price.

### Sell Order Book

<table>
<thead>
<tr>
<th>Sell Price</th>
<th>Buy Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>84</td>
<td>101</td>
</tr>
<tr>
<td>176</td>
<td>100</td>
</tr>
</tbody>
</table>

### Buy Limit

<table>
<thead>
<tr>
<th>Sell Price</th>
<th>Buy Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>99</td>
<td>2</td>
</tr>
<tr>
<td>98</td>
<td>77</td>
</tr>
</tbody>
</table>

- **Market Order**: Order executed immediately.
- **Limit Order**: Order not executed immediately.

Agents decide an order price, if there exists a matching order, execute a market order; otherwise, execute a limit order.
$\delta l / \delta o > 2$ : be Inefficient significantly