A Brief Review of recent Artificial Market Simulation (Agent-Based Model) Studies for Financial Market Regulations and/or Rules

Takanobu Mizuta

SPARX Asset Management Co., Ltd.

It is very difficult to discuss about changing financial market regulations and/or rules by only using results of empirical studies. An artificial market, which is a kind of an agent-based model, can isolate the pure contribution of changing the regulations to the price formation and can treat situations that have never occurred. These are strong points of the artificial market simulation study. Recently, some artificial market studies contributed to discussion what financial regulations and rules should be, for example, price variation limits and short selling regulation whether preventing bubbles and crushes or not, tick size, usage rate of dark pools, rules for investment diversification, speed of order matching systems on financial exchanges, frequent batch auctions, how active funds that trade infrequently make a market more efficient, an interaction between leveraged ETF markets and underlying markets and micro-foundation of price variation model using intelligence of artificial market simulation studies. I will review those studies.

1. Artificial Market Simulation

It is very difficult to discuss about changing financial market regulations and/or rules only by results of empirical studies. Because so many factors cause price formation in actual markets, an empirical study cannot isolate the pure contribution of existing new type regulations or of changing rules to price formation. Furthermore, empirical studies cannot investigate situations that have never occurred before in real financial markets.

We usually discuss whether regulations should be changed or not on the basis of their effects on price formation. An artificial market, which is a kind of a multi-agent simulation (an agent based model), can isolate the pure contribution of changing the regulations to the price formation and can treat situations that have never occurred [LeBaron 06, Chen 12, Cristelli 14, Todd 16]. These are strong points of the artificial market simulation study.

Not only academies but also financial regulators and stock exchanges are recently interested in multi-agent simulations such artificial market models to investigate regulations and rules of financial markets. Indeed, the Science article [Battiston 16] described that 'since the 2008 crisis, there has been increasing interest in using ideas from complexity theory (using network models, multi-agent models, and so on) to make sense of economic and financial markets', and the Nature article [Farmer 09] described that 'such (agent based) economic models should be able to provide an alternative tool to give insight into how government policies could affect the broad characteristics of economic performance, by quantitatively exploring how the economy is likely to react under different scenarios'. [Aruka 17] also claimed importance of an artificial market simulation.

Recently, some artificial market studies contributed to discussion what financial regulations and rules should be [Todd 16], for example, price variation limits and short selling regulation whether preventing bubbles and crushes or not [Yagi 10, Yeh 10, Mizuta 13b, Mizuta 15b, Mizuta 16c, Veld 16, Zhang 16], the rule for investment diversification [Yagi 17], transaction taxes [Westerhoff 08, Veryzhenko 17], financial leverages [Thurner 12, Veld 16], circuit breakers [Kobayashi 11], tick size [Mizuta 13a], frequent batch auctions [Mizuta 16a], usage rate of dark pools [Mo 13, Mizuta 14, Mizuta 15c], speed of order matching systems on financial exchanges [Mizuta 15a, Mizuta 16d], the effects of different regulatory policies directed towards high frequency traders (HFTs) [Leal 16], effects of Basel and value at risk [Cheng 17, Llacay 17], one-sided and two-sided markets [Zhou 17], settlement cycle [Xiong 17] and so on. Of course, many artificial market simulation studies investigated the nature of financial markets, how active funds that trade infrequently make a market more efficient [Mizuta 17], investigation of interaction between leveraged ETF markets and underlying markets to price formation using artificial market simulations [Yagi 16], micro-foundation of price variation model using intelligence of artificial market simulation studies [Mizuta 16b] and so on[*1]. I will review some of those studies on the next section.

The artificial market simulation models simulate macro processes such as investors and order matching on a computer. Artificial market studies observe macro phenomena

Contact: mizutata@gmail.com
http://www.mizutatakanobu.com/

*1 For examples, market efficiency [Immonen 17, Pruna 16, Tsao 17], market impacts [Cui 12, Oesch 14], trading volume and price distortion [Lespagnol 17], financial market crush [Yagi 12, Paddrik 12, Torii 15, Schmitt 16, Benhammada 17], market liquidities on the network of banks [Sakiyama 16], immature markets [Krichene 16], interaction between option markets and underlying markets [Kawakubo 14a, Kawakubo 14b], effects of market makers and passive funds [Braun-Munzinger 16], effects of HFTs [Gsell 09, Wang 13, Kusada 14, Xiong 15, Hanson 16], effects of arbitrage trading between markets that have different latencies [Wah 13, Wah 16, Wellman 17], an information diffusion on investors' multi-later networks [Biondo 16, Alsulaiman 17, Zhang 17, Biondo 17], role of behavioral heterogeneity [Hessary 17] and an investor network and herding [Jiménez Bermúdez 16, Krichene, Wang 17]. [Kita 16] reviewed the U-Mart project which is one of Japanese top artificial market research projects in the 2000s.

such as price variations as a result of the modeled macro processes. Artificial market models only modelize the micro processes and observe macro phenomena, therefore, artificial market models are fully micro-founded models. So, artificial market models have been gaining intelligence micro-macro interaction mechanisms such as what micro processes amplify price variations.

An artificial market can isolate the direct effect of changes the regulations to price formation, and can treat situations that have never occurred. However, outputs of artificial market simulations may not be accurate or credible forecasts in actual markets. It is an important for artificial market simulations to show possible mechanisms affecting price formation through many runs and gain new knowledge; conversely, a limitation of artificial market simulations is that their outputs may, but not certainly, occur in actual financial markets.

Therefore, for more detailed discussions, they should compare the simulation results to those from studies using other methods, e.g. empirical studies, would not show such possible mechanisms. Indeed, artificial markets should replicate macro phenomena existing generally for any asset and any time. Price variation, which is a kind of macro phenomena, is not explicitly modeled in artificial markets. Only micro processes, agents (general investors), and price determination mechanisms (financial exchanges) are explicitly modeled in artificial markets. Macro phenomena are emerging as the outcome interactions of micro processes. Therefore, the simulation outputs should replicate general macro phenomena at least to show that simulation models are probable in actual markets.

However, it is not a primary purpose for the artificial market to replicate specific macro phenomena only for a specific asset or a specific period. An unnecessary replication of macro phenomena leads to models that are over-fitted and too complex. Such models would prevent our understanding and discovering mechanisms affecting the price formation because of related factors increasing.

Indeed, artificial market models that are too complex are often criticized because they are very difficult to evaluate [Chen 12]. A too complex model not only would prevent our understanding mechanisms but also could output arbitrary results by over-fitting too many parameters. Simpler models harder obtain arbitrary results, and are easier evaluated.

Therefore, previous studies constructed an artificial market models that are as simple as possible and do not intentionally implement agents to cover all the investors who would exist in actual financial markets.

The next section, I review some of recent artificial market studies for financial market regulations and/or rules.

2. Recent Studies for Financial Market Regulations and/or Rules

2.1 Bubble, Crash, Price Variation Limit and Short Selling Regulation

[Mizuta 13b] built an artificial market model, based on the model of [Chiarella 02], implementing a learning process to replicate bubbles and investigated a price variation limit whether preventing bubbles and crush or not. The price variation limits are expected to be an especially effective way to prevent bubbles, so the model should be able to replicate bubbles.

When they gave a bubble-inducing trigger, which is a rapid increment of the fundamental value, a bubble occurred in the case with the model implementing the learning process but did not occur in the case without the process. They also showed that a hazard rate enables verification of whether the models can replicate a bubble process or not.

[Mizuta 15b] built an artificial market model, based on the model of [Chiarella 02], and compared effects of price variation limits, short selling regulations and up-tick rules.

In the case without the regulations, the price fell to below a fundamental value when an economic crush occurred. On the other hand, in the case with the regulations, this overshooting did not occur. However, the short selling regulation and the up-tick rule caused the trading prices to be higher than the fundamental value.

They also surveyed an adequate limitation price range and an adequate limitation time span for the price variation limit and found a parameters' condition of the price variation limit to prevent the over-shorts. They also showed the limitation price range should be bigger than a volatility calculated by the limitation time span.

[Mizuta 16c] investigated effects of price variation limits and up-tick rules in large price fluctuation turbulence caused by large erroneous orders, and investigated whether dark pools stabilize markets or not.

They found that the amount of erroneous orders decided ranges of price falls. They also found that the limited time span of price variation limits should be shorter than the time of erroneous orders existing to prevent large turbulence. For the effects of up-tick rules adopting a trigger method they found that in the cases with time unlock, effect time of the up-tick rule is not very different from the time of erroneous orders existing, and this prevents large turbulence. In the case with price unlock, the rules prevent large turbulence in all cases.

Because we cannot forecast how long an investor would erroneous order in actual financial markets, it is implied that actual stock markets should employ several price variation limits that have different limited time spans. Tokyo Stock Exchange employs two kinds of price variation limits that adopt different time spans: one is daily price limit, 300 minutes and the other is special quote, 3 minutes. It is implied that Tokyo Stock Exchange should employ another price variation limit having shorter limited time spans than 1 minutes because HFTs (High Frequency Trading) are increasing recently.

The results investigating the up-tick rules suggest that the price unlock is a better unlock method than time unlock, which the Japan Financial Services Agency adopted on November 2013. However, more detail discussion would be future study.

2.2 Rule for Investment Diversification

As financial products have grown in complexity and level of risk compounding in recent years, investors have come to find it difficult to assess investment risk. Furthermore, companies managing mutual funds are increasingly expected to perform risk control and thus prevent assumption of unforeseen risk by investors. A related revision to the mutual fund legal system in Japan led to establishing what is known as "the rule for investment diversification" in December 2014, without a clear discussion of its expected effects on market price formation having taken place. [Yagi 17, Nozaki 17] used an artificial market to investigate its effects on price formation in financial markets where investors must follow the rule at the time of a market crash that was caused by the collapse of the asset fundamental price. As results, they found that, in a two-asset market where investors had to follow the rule for investment diversification, when the fundamental price of one asset collapsed and its market price also collapsed, the other asset market price also fell [Yagi 17]. They also found that the possibility that when the fundamental price of one asset collapses and its market price also collapses, some asset market prices also fall, whereas other asset market prices rise for a market in which investors follow the rule for investment diversification [Nozaki 17].

2.3 Tick Size

[Mizuta 13a] investigated competition, in terms of taking market share of trading volume between two artificial financial markets that had exactly the same specifications except tick size and initial trading volume using multi-agents simulations.

When the tick size of market A, ΔP_A, was larger than approximately the standard deviation of tick by tick return, $\overline{\sigma_t}$, if the tick size of market B, ΔP_B, was enough smaller than ΔP_A, much trading occurred in market B inside ΔP_A. Therefore, market B took market share of the trading volume from market A.

On the other hand, when ΔP_A was smaller than approximately $\overline{\sigma_t}$, even if ΔP_B was very small, price fluctuations cross many widths of ΔP_A and enough price formations occurred only in market A. Therefore, market B could rarely take market share of trading volume from market A.

They also compared these simulation results with empirical data from the Tokyo Stock Exchange. They argued that this investigation will enable discussion about the adequate tick sizes markets should adopt.

2.4 Frequent Batch Auctions

[Mizuta 16a] implemented a price mechanism that is changeable between a comparable continuance double auction (CDA, $\delta t = 1$) and a frequent batch auction (FBA, $\delta t > 1$) continuously introducing a new parameter, a batch auction interval δt. And then, they analyzed profits/losses and risks of market maker strategies (MM) and investigated whether MM can continue to provide liquidity even on FBA by using an artificial market model.

Their simulation results showed that δt is larger, execution rates of MM is smaller and this causes to reduce liquidity supply by MM. Furthermore, they suggested that when δt is larger (FBA), MM cannot avoid both an overnight risk and a price variation risk intraday. Furthermore, they also suggested that when $\delta t > 1$ (FBA) it is very difficult that MM is rewarded for risks and continue to provide liquidity. Only the case of $\delta t = 1$ (CDA) MM is rewarded for risks and continue to provide liquidity.

These suggestions implies that MM that can provide liquidity on CDA cannot continue to provide liquidity on FBA and then many MM retire, and finally liquidity will be reduced. This implication is consistent with the argument by [Otsuka 14, Melton 17].

2.5 Dark Pool

[Mizuta 15c] investigated how a dark pool, in which no order books are provided, affects financial markets' efficiency and price-discovery function by using the artificial market model. This is a very important investigation into financial systemic risk because making a market inefficient and losing the price-discovery function may make the market unstable and increase financial systemic risk. In this study, they additionally implemented a smart order routing (SOR) to treat actual market selection of investors. They discussed quantitatively how spreading of dark pools beyond our experience could affect the price-discovery function. They also aimed to clarify the mechanism of a dark pool that makes a market efficient or inefficient.

They found that market inefficiently (M_{ie}) was decreased sharply by raising the share of the trading value amount of the dark pool (D) in $D \lesssim 70\%$. On the other hand, in $D \gtrsim 70\%$, M_{ie} increased significantly. This indicates that there is an optimal usage rate of the dark pool for the market efficiency.

The reason M_{ie} decreased in $D \lesssim 70\%$ is that the execution rates in the lit market are reduced by more market orders being sent to the dark pool by the SOR than limit orders increasing D. This leads the depth of limit orders to become thicker, these thicker limit orders absorb market orders, and thus the market price is still stable near the fundamental price.

The reason M_{ie} increased significantly in $D \gtrsim 70\%$ is as follows. When a market price (P^t) becomes much higher than the fundamental price (P_f), many waiting buy orders are stored in the dark pool and averaged estimated returns ($r^t_{e,j}$) for all agents are negative, which means that agents make market sell orders. These market sell orders could have made P^t converge to P_f, but many waiting buy orders stored in the dark pool absorb these market sell orders and prevent P^t converging to P_f. Therefore, P^t maintains a much higher price than P_f, and the lit market is made inefficient. When P^t becomes much lower than P_f, the opposite occurs.

They also discussed mechanisms by which a dark pool makes a market efficient or inefficient by a simple equation model. The equations about an execution rate they derived indicate that whether $D > 1/2$ or $D < 1/2$ is intrinsically important to whether markets become efficient or inefficient. Therefore, this suggests that the optimal usage rate of the dark pool for the market efficiency is $D = 1/2$ and that a trading volume amount in dark pools higher than that in lit markets makes markets inefficient. They also compared results of the equations with those of simulations and found similar tendencies.

They also derived an equation showing the boundary of a buy-sell imbalance at which dark pools destroy the price-discovery function. They also discussed that when the usage rate of dark pools is low, for example $D = 20\%$, the equation suggests that dark pools rarely destroy the price-discovery function even though a large buy-sell imbalance occurs. On the other hand, when the usage rate of dark pools is very high, for example $D = 90\%$, this equation suggests that dark pools very easily destroy the price-discovery function by a very slight buy-sell imbalance.

A future study is to investigate more details of the optimal usage rate of dark pools for the market efficiency. Our results suggested the optimal usage rate was around $50\% - 70\%$, which is much higher than about 8%, which is the cap level of dark pools that European regulators are discussing. However, they could not determine the precise level of the optimal usage rate of dark pools for the market efficiency.

Another future study is comparing the simulation results with empirical data. Indeed, they cannot observe M_{ie} of real markets by empirical data because they cannot find fundamental prices in real markets. On the other hand, they can observe an execution rate, depth of limit orders and a bid ask spread of each stock in real lit markets from empirical data. In addition, they can estimate D of each stock from some statistics. D are different from one stock to another. Therefore they can draw figures from empirical data plotting each stock having different D, execution rates and so on. To compare these figures with simulation results, they can compare the simulation results with empirical data.

They also observe buy-sell imbalances in real lit markets from empirical data. They can discuss how much D may destroy the price-discovery function in real financial markets.

2.6 Increasing Speed of Order Matching Systems on Financial Exchanges

[Mizuta 15a, Mizuta 16d] constructed a simple artificial market model in which the latency was implemented and investigated price formations and market efficiency for various latencies. They clarify the mechanisms of the direct effects of latency on financial market efficiency and discuss how much of an increase in speed is needed for market efficiency.

If the latency is large, agents cannot quickly change their estimated prices when the market trend has finished. Agents then make unnecessary market orders, and such market orders increase the execution rate. They argued that increasing the execution rate reduces limit orders to near the market price, widens the bid ask spread, and makes the market becomes less efficient. This indicates that latency should be sufficiently smaller than the average order interval for a market to be efficient.

The largest contribution of this study was the possibly that a large latency (too slow of a matching system) would directly make market price formation inefficient. Therefore, too slow of a matching system might destabilize a market. This implication is generally opposite to that in which the increase in the speed of matching systems might destabilize financial markets.

They also analyzed empirical data of the Tokyo Stock Exchange and compared the results with simulation results. It is possible that the market was chronically inefficient during a large portion of trading time due to the latency before the introduction of new trading system, “arrowhead”, from 2010 in the Tokyo Stock Exchange. On the other hand, the market is not chronically inefficient due to the latency at least for a time scale of minutes after the introduction of arrowhead.

For future work, they will investigate the case of a large amount of orders for less than one minute after very important news. They did not consider this case for specific and very short spans in the simulations of this study. They implemented only normal agents replicating general investors; however, latency was more important, especially for HFTs whose investment strategies are market maker, arbitrage, and so on. They should discuss the latencies for different types of agents for future work.

2.7 Effects of several Regulations directed towards HFTs

[Leal 16] constructed an agent-based model to analyze the effectiveness of a set of regulatory policies on market volatility, and on the occurrence and the duration of flash crashes. analyzed the impact of policies trading halt facilities (both ex-post and ex-ante designs), minimum resting times, order cancellation fees, and transaction taxes. These policies have been proposed and implemented in many developed countries to prevent flash crashes.

Simulations results showed that, policies slowing down the order cancellation of HFTs, like the implementation of minimum resting times or cancellation fees lead to significant improvements in terms of lower market volatility and incidence of flash crashes. Also the introduction of a financial transaction tax, by discouraging HFTs, can improve market stability, although the effectiveness of such a measure is much lower compared to policies targeting order cancellation, and effects are relevant only for high values of the tax.

At the same time, all these policies are characterized by a trade-off between market stability (in terms of lower volatility and number of flash crashes) and market resilience (in terms of longer recoveries from a crash). This trade-off emerges because of the positive role played by HFTs in quickly restoring good liquidity conditions after a crash. Regulatory policies introduce important distortions in such a process, thereby contributing to lengthen the duration of price-recoveries. The beneficial impact of HFTs on price resilience also underlies the results concerning the study of the impact of circuit breakers, and in particular explain why ex-post circuit breakers have no effect on volatility and have a negative impact on the duration of flash crashes. In contrast, they found that ex-ante circuit breakers are very effective, as they markedly reduce price volatility and completely remove flash crashes.

Overall, simulation results suggest that regulatory policies can have quite complex effects on markets populated by normal investors and HFTs. From the viewpoint of policy design, our analysis highlights in particular the importance of understanding the different transmission mechanisms through which the effects of regulatory policies unfold. Moreover, it points out the need of taking into account the fundamental dual role played by HFTs. On the one hand, HFTs can be the source of extreme events like flash crashes by placing aggressive sell orders and removing liquidity from the market. On the other hand, it can play a leading role in the recovery from the crash, by quickly restoring liquidity.

3. Some Recent Studies for the Nature of Financial Markets

3.1 How active funds that trade infrequently make a market more efficient

Since managers of active funds choose stocks that are expected to raise their prices on the basis of the fundamental value, many argue that active funds discover the fundamental value and make a market more efficient. However, it has not been clear whether actual active funds make a market more efficient or not. It has been shown that active funds that trade infrequently earn more. At first glance, infrequent trades seem to not impact and change market prices and this leads to market prices not converging with the fundamental price. Therefore, it is important to discuss whether active funds that trade infrequently make a market more efficient or not, and if so, we should investigate the mechanism of how they do so.

[Mizuta 17] built a model of investors who trade infrequently in an artificial market model, and they investigated effects of these investors on market prices and whether they make a market more efficient by using the model.

The results indicated that such active investors trade frequently in the rare situation that the market becomes unstable and inefficient due to the market price moving away from the fundamental price. These trades, occurring only at a necessary time, impact the market prices and lead them converging with the fundamental price. This leads preventing the market from becoming more unstable and less efficient.

Though the trading volume of fundamental investors is low throughout whole period, the volume increases greatly only when a market becomes less efficient, and these trades then make the market efficient. An increasing market volatility makes the order prices of speculators (technical investors) move further away from the fundamental price, and this leads to amplifying market volatility more excessively.

It is possible that the orders of active investors prevent this amplification. This also implies that money moving from active funds to passive funds leads a market to become less efficient.

3.2 Interaction between a Leveraged ETF and an Underlying

[Yagi 16] built an artificial market model, based on the model of [Yagi 10], implementing rebalancing trades of a leveraged ETF, and investigated impact of the rebalancing trades on the price formation of future index (underlying asset) market. They found that a market impact (MI) per a volatility (V) is very important key parameter, when MI $<$ V the index future market becomes stable, on the other hand when MI $>$ V the index future market becomes unstable. They also showed the possible mechanism of such destabilizing market.

3.3 Micro-Foundation of Price Variation Model

[Mizuta 16b] tried micro-foundation of the ARCH(1) model, which is a kind of financial risk asset price variation model, using intelligence of artificial market simulation studies. That is they tried to clarify which micro processes determine each coefficient of the ARCH(1) model. Then they obtained,

$$\sigma_t^2 = \rho^2 k^2 + 2\rho^2 k^2 \frac{l}{\alpha} r_{t-1}^2. \tag{1}$$

The dispersion of investors' estimated prices(ρ) is larger or the orders by the buy-sell imbalance taking liquidity(k) is larger, the volatility is larger. The ration of the normal investors taking liquidity to the normal traders providing liquidity(l) is higher or the measure of risk aversion of the normal investors(α) is lower, the magnitude of volatility clustering is larger.

There are two future works. One is an empirical study validating our model. Another one is more detail discussion of our assumptions that are too strong assumptions for real financial markets.

Disclaimer

Note that the opinions contained herein are solely those of the authors and do not necessarily reflect those of SPARX Asset Management Co., Ltd.

Reference

[Alsulaiman 17] Alsulaiman, T. and Khashanah, K.: *Network of Networks: A Meta-model for Simulated Financial Markets*, pp. 671–682, Springer International Publishing, Cham (2017), `http://dx.doi.org/10.1007/978-3-319-50901-3_53`

[Aruka 17] Aruka, Y.: Special feature: preliminaries towards ontological reconstruction of economics—theories and simulations, *Evolutionary and Institutional Economics Review*, Vol. 14, No. 2, pp. 409–414 (2017), `https://doi.org/10.1007/s40844-017-0088-z`

[Battiston 16] Battiston, S., Farmer, J. D., Flache, A., Garlaschelli, D., Haldane, A. G., Heesterbeek, H., Hommes, C., Jaeger, C., May, R., and Scheffer, M.: Complexity theory and financial regulation, *Science*, Vol. 351, No. 6275, pp. 818–819 (2016), `http://science.sciencemag.org/content/351/6275/818`

[Benhammada 17] Benhammada, S., Amblard, F., and Chikhi, S.: An Asynchronous Double Auction Market to Study the Formation

of Financial Bubbles and Crashes, *New Generation Computing*, Vol. 35, No. 2, pp. 129–156 (2017),
http://dx.doi.org/10.1007/s00354-017-0010-6

[Biondo 16] Biondo, A. E., Pluchinob, A., and Rapisardab, A.: A Multi-layer Model of Order Book Dynamics, in *57th Annual Conference Bocconi University* (2016),
http://www.siecon.org/online/wp-content/uploads/2016/09/BIONDO.pdf

[Biondo 17] Biondo, A. E., Pluchino, A., and Rapisarda, A.: Informative Contagion Dynamics in a Multilayer Network Model of Financial Markets, *Italian Economic Journal*, pp. 1–24 (2017),
http://dx.doi.org/10.1007/s40797-017-0052-4

[Braun-Munzinger 16] Braun-Munzinger, K., Liu, Z., and Turrell, A.: Staff Working Paper No. 592 An agent-based model of dynamics in corporate bond trading, *Bank of England, Staff Working Papers* (2016),
http://www.bankofengland.co.uk/research/Pages/workingpapers/2016/swp592.aspx

[Chen 12] Chen, S.-H., Chang, C.-L., and Du, Y.-R.: Agent-based economic models and econometrics, *Knowledge Engineering Review*, Vol. 27, No. 2, pp. 187–219 (2012),
http://dx.doi.org/10.1017/S0269888912000136

[Cheng 17] Cheng, F. and Wellman, M. P.: Accounting for Strategic Response in an Agent-Based Model of Financial Regulation, in *Proceedings of the 2017 ACM Conference on Economics and Computation*, EC '17, pp. 187–203, New York, NY, USA (2017), ACM,
http://doi.acm.org/10.1145/3033274.3085114

[Chiarella 02] Chiarella, C. and Iori, G.: A simulation analysis of the microstructure of double auction markets, *Quantitative Finance*, Vol. 2, No. 5, pp. 346–353 (2002),
http://www.tandfonline.com/doi/abs/10.1088/1469-7688/2/5/303

[Cristelli 14] Cristelli, M.: *Complexity in Financial Markets, Modeling Psychological Behavior in Agent-Based Models and Order Book Models*, Springer (2014),
https://dx.doi.org/10.1007/978-3-319-00723-6

[Cui 12] Cui, W. and Brabazon, A.: An agent-based modeling approach to study price impact, in *Computational Intelligence for Financial Engineering Economics (CIFEr), 2012 IEEE Conference on*, pp. 1–8 (2012),
http://dx.doi.org/10.1109/CIFEr.2012.6327798

[Farmer 09] Farmer, J. D. and Foley, D.: The economy needs agent-based modelling, *Nature*, Vol. 460, No. 7256, pp. 685–686 (2009),
https://www.nature.com/articles/460685a

[Gsell 09] Gsell, M.: Assessing the impact of algorithmic trading on markets: a simulation approach, *Center for Financial Studies (CFS) Working Paper* (2009),
http://aisel.aisnet.org/cgi/viewcontent.cgi?article=1076&context=ecis2008

[Hanson 16] Hanson, T. A. and Hanson, T. A.: High frequency traders in a simulated market, *Review of Accounting and Finance*, Vol. 15, No. 3, pp. 329–351 (2016),
http://dx.doi.org/10.1108/RAF-02-2015-0023

[Hessary 17] Hessary, Y. K. and Hadzikadic, M.: Role of Behavioral Heterogeneity in Aggregate Financial Market Behavior: An Agent-Based Approach, *Procedia Computer Science*, Vol. 108, pp. 978 – 987 (2017), International Conference on Computational Science, ICCS 2017, 12-14 June 2017, Zurich, Switzerland

[Immonen 17] Immonen, E.: Simple agent-based dynamical system models for efficient financial markets: Theory and examples, *Journal of Mathematical Economics* (2017),
http://dx.doi.org/10.1016/j.jmateco.2016.12.005

[Jiménez Bermúdez 16] Jiménez Bermúdez, A.: The effect of herding in financial markets (2016),
http://hdl.handle.net/10234/165063

[Kawakubo 14a] Kawakubo, S., Izumi, K., and Yoshimura, S.: Analysis of an Option Market Dynamics based on a Heterogeneous Agent Model, *Intelligent Systems in Accounting, Finance and Management*, Vol. 21, No. 2, pp. 105–128 (2014),
http://dx.doi.org/10.1002/isaf.1353

[Kawakubo 14b] Kawakubo, S., Izumi, K., and Yoshimura, S.: How Does High Frequency Risk Hedge Activity Have an Affect on Underlying Market? : Analysis by Artificial Market Model, *Journal of advanced computational intelligence and intelligent informatics*, Vol. 18, No. 4, pp. 558–566 (2014),
http://dx.doi.org/10.20965/jaciii.2014.p0558

[Kita 16] Kita, H., Taniguchi, K., and Nakajima, Y.: *Realistic Simulation of Financial Markets*, Springer (2016),
https://dx.doi.org/10.1007/978-4-431-55057-0

[Kobayashi 11] Kobayashi, S. and Hashimoto, T.: Benefits and Limits of Circuit Breaker: Institutional Design Using Artificial Futures Market, *Evolutionary and Institutional Economics Review*, Vol. 7, No. 2, pp. 355–372 (2011),
http://dx.doi.org/10.14441/eier.7.355

[Krichene] Krichene, H. and El-Aroui, M.-A.: Artificial stock markets with different maturity levels: simulation of information asymmetry and herd behavior using agent-based and network models:
http://dx.doi.org/10.1007/s11403-017-0191-6

[Krichene 16] Krichene, H. and El-Aroui, M.-A.: Agent-Based Simulation and Microstructure Modeling of Immature Stock Markets, *Computational Economics*, pp. 1–19 (2016),
http://dx.doi.org/10.1007/s10614-016-9615-y

[Kusada 14] Kusada, Y., Mizuta, T., Hayakawa, S., and Izumi, K.: Impacts of Position-Based Market Makers on Markets' Shares of Trading Volumes - An Artificial Market Approach, in *Social Modeling and Simulations + Econophysics Colloquium 2014* (2014),
http://aph.t.u-tokyo.ac.jp/smsec2014/program-2/contributed-talks-posters/

[Leal 16] Leal, S. J. and Napoletano, M.: Market Stability vs. Market Resilience: Regulatory Policies Experiments in an Agent Based Model with Low-and High-Frequency Trading, Technical report, Laboratory of Economics and Management (LEM), Sant'Anna School of Advanced Studies, Pisa, Italy (2016),
http://www.lem.sssup.it/WPLem/2016-15.html

[LeBaron 06] LeBaron, B.: Agent-based computational finance, *Handbook of computational economics*, Vol. 2, pp. 1187–1233 (2006),
http://dx.doi.org/10.1016/S1574-0021(05)02024-1

[Lespagnol 17] Lespagnol, V. and Rouchier, J.: Trading Volume and Price Distortion: An Agent-Based Model with Heterogenous Knowledge of Fundamentals, *Computational Economics*, pp. 1–30 (2017)

[Llacay 17] Llacay, B. and Peffer, G.: Impact of value-at-risk models on market stability, *Journal of Economic Dynamics and Control*, Vol. 82, pp. 223 – 256 (2017)

[Melton 17] Melton, H.: Market Mechanism Refinement on a Continuous Limit Order Book Venue: A Case Study, *SIGecom Exch.*, Vol. 16, No. 1, pp. 72–77 (2017),
http://doi.acm.org/10.1145/3144722.3144729

[Mizuta 13a] Mizuta, T., Hayakawa, S., Izumi, K., and Yoshimura, S.: Investigation of Relationship between Tick Size and Trading Volume of Markets using Artificial Market Simulations, in *JPX working paper*, No. 2, Japan Excgange Group (2013),
http://www.jpx.co.jp/english/corporate/research-study/working-paper/

[Mizuta 13b] Mizuta, T., Izumi, K., and Yoshimura, S.: Price variation limits and financial market bubbles: Artificial market simulations with agents' learning process, in *Computational Intelligence for Financial Engineering Economics (CIFEr), 2013 IEEE Conference on*, pp. 1–7 (2013),
http://dx.doi.org/10.1109/CIFEr.2013.6611689

[Mizuta 14] Mizuta, T., Kosugi, S., Kusumoto, T., Matsumoto, W., Izumi, K., and Yoshimura, S.: Do Dark Pools make Markets Stable and Reduce Market Impacts? ∼ Investigations using Multi Agent Simulations ∼, in *Computational Intelligence for Financial Engineering Economics (CIFEr), 2014 IEEE Conference on*, pp. 71–76 (2014),
http://dx.doi.org/10.1109/CIFEr.2014.6924056

[Mizuta 15a] Mizuta, T., Noritake, Y., Hayakawa, S., and Izumi, K.: Impacts of Speedup of Market System on Price Formations using Artificial Market Simulations, in *JPX working paper*, No. 9, Japan Excgange Group (2015),
http://www.jpx.co.jp/english/corporate/research-study/working-paper/

[Mizuta 15b] Mizuta, T., Izumi, K., Yagi, I., and Yoshimura, S.: Investigation of Price Variation Limits, Short Selling Regulation, and Uptick Rules and Their Optimal Design by Artificial Market Simulations, *Electronics and Communications in Japan*, Vol. 98, No. 7, pp. 13–21 (2015),
http://dx.doi.org/10.1002/ecj.11684

[Mizuta 15c] Mizuta, T., Kosugi, S., Kusumoto, T., Matsumoto, W., and Izumi, K.: Effects of dark pools on financial markets' efficiency and price discovery function: an investigation by multi-agent simulations, *Evolutionary and Institutional Economics Review*, Vol. 12, No. 2, pp. 375–394 (2015), http://dx.doi.org/10.1007/s40844-015-0020-3

[Mizuta 16a] Mizuta, T. and Izumi, K.: Investigation of Frequent Batch Auctions using Agent Based Model, in *JPX working paper*, No. 17, Japan Excgange Group (2016), http://www.jpx.co.jp/english/corporate/research-study/working-paper/

[Mizuta 16b] Mizuta, T.: Micro-Foundation of ARCH Model, *SSRN Working Paper Series* (2016), http://ssrn.com/abstract=2710457

[Mizuta 16c] Mizuta, T., Kosugi, S., Kusumoto, T., Matsumoto, W., Izumi, K., Yagi, I., and Yoshimura, S.: Effects of Price Regulations and Dark Pools on Financial Market Stability: An Investigation by Multiagent Simulations, *Intelligent Systems in Accounting, Finance and Management*, Vol. 23, No. 1-2, pp. 97–120 (2016), http://dx.doi.org/10.1002/isaf.1374

[Mizuta 16d] Mizuta, T., Noritake, Y., Hayakawa, S., and Izumi, K.: Affecting market efficiency by increasing speed of order matching systems on financial exchanges - investigation using agent based model, in *Computational Intelligence for Financial Engineering Economics (CIFEr), 2016 IEEE Symposium Series on Computational Intelligence on* (2016), https://doi.org/10.1109/SSCI.2016.7850002

[Mizuta 17] Mizuta, T. and Horie, S.: Why do Active Funds that Trade Infrequently Make a Market more Efficient? - Investigation using Agent-Based Model, in *Computational Intelligence for Financial Engineering Economics (CIFEr), 2017 IEEE Symposium Series on Computational Intelligence on* (2017), https://doi.org/10.1109/SSCI.2017.8280798

[Mo 13] Mo, S. Y. K. and Yang, M. P. S. Y.: A Study of Dark Pool Trading using an Agent-based Model, in *Computational Intelligence for Financial Engineering Economics (CIFEr), 2013 IEEE Symposium Series on Computational Intelligence on*, pp. 19–26 (2013), http://dx.doi.org/10.1109/CIFEr.2013.6611692

[Nozaki 17] Nozaki, A., Mizuta, T., and Yagi, I.: A Study on the Market Impact of the Rule for Investment Diversification at the Time of a Market Crash Using a Multi-Agent Simulation, *IEICE Transactions on Information and Systems*, Vol. E100.D, No. 12, pp. 2878–2887 (2017), https://doi.org/10.1587/transinf.2016AGP0003

[Oesch 14] Oesch, C.: An agent-based model for market impact, in *Computational Intelligence for Financial Engineering Economics (CIFEr), 2104 IEEE Conference on*, pp. 17–24 (2014), http://dx.doi.org/10.1109/CIFEr.2014.6924049

[Otsuka 14] Otsuka, T.: High Frequency Trading and the Complexity of the U.S. Equities Market (Japanese only), in *JPX Working Paper*, No. Special Report, Japan Exchange Group (2014), http://www.jpx.co.jp/english/corporate/research-study/working-paper/

[Paddrik 12] Paddrik, M., Hayes, R., Todd, A., Yang, S., Beling, P., and Scherer, W.: An agent based model of the E-Mini S amp;P 500 applied to flash crash analysis, in *Computational Intelligence for Financial Engineering Economics (CIFEr), 2012 IEEE Conference on*, pp. 1–8 (2012), http://dx.doi.org/10.1109/CIFEr.2012.6327800

[Pruna 16] Pruna, R. T., Polukarov, M., and Jennings, N. R.: An asset pricing model with loss aversion and its stylized facts, in *Computational Intelligence for Financial Engineering Economics (CIFEr), 2016 IEEE Symposium Series on Computational Intelligence on* (2016), https://doi.org/10.1109/SSCI.2016.7850003

[Sakiyama 16] Sakiyama, T. and Yamada, T.: Market Liquidity and Systemic Risk in Government Bond Markets: A Network Analysis and Agent-Based Model Approach, *Discussion Paper Series*, No. E-13 (2016), http://www.imes.boj.or.jp/research/abstracts/english/16-E-13.html

[Schmitt 16] Schmitt, N. and Westerhoff, F.: Heterogeneity, spontaneous coordination and extreme events within large-scale and small-scale agent-based financial market models, No. 111 (2016), https://www.econstor.eu/handle/10419/144607

[Thurner 12] Thurner, S., Farmer, J., and Geanakoplos, J.: Leverage causes fat tails and clustered volatility, *Quantitative Finance*, Vol. 12, No. 5, pp. 695–707 (2012), http://dx.doi.org/10.1080/14697688.2012.674301

[Todd 16] Todd, A., Beling, P., Scherer, W., and Yang, S. Y.: Agent-based financial markets: A review of the methodology and domain, in *Computational Intelligence for Financial Engineering Economics (CIFEr), 2016 IEEE Symposium Series on Computational Intelligence on* (2016), https://doi.org/10.1109/SSCI.2016.7850016

[Torii 15] Torii, T., Izumi, K., and Yamada, K.: Shock transfer by arbitrage trading: analysis using multi-asset artificial market, *Evolutionary and Institutional Economics Review*, Vol. 12, No. 2, pp. 395–412 (2015), http://dx.doi.org/10.1007/s40844-015-0024-z

[Tsao 17] Tsao, C.-Y. and Huang, Y.-C.: Revisiting the issue of survivability and market efficiency with the Santa Fe Artificial Stock Market, *Journal of Economic Interaction and Coordination*, pp. 1–24 (2017), http://dx.doi.org/10.1007/s11403-017-0192-5

[Veld 16] Veld, D. i.: Adverse effects of leverage and short-selling constraints in a financial market model with heterogeneous agents, *Journal of Economic Dynamics and Control*, Vol. 69, pp. 45 – 67 (2016), http://dx.doi.org/10.1016/j.jedc.2016.05.005

[Veryzhenko 17] Veryzhenko, I., Arena, L., Harb, E., and Oriol, N.: Time to Slow Down for High-Frequency Trading? Lessons from Artificial Markets, *Intelligent Systems in Accounting, Finance and Management*, pp. n/a–n/a (2017), http://dx.doi.org/10.1002/isaf.1407

[Wah 13] Wah, E. and Wellman, M. P.: Latency arbitrage, market fragmentation, and efficiency: a two-market model, in *Proceedings of the fourteenth ACM conference on Electronic commerce*, pp. 855–872ACM (2013), http://dl.acm.org/citation.cfm?id=2482577

[Wah 16] Wah, E. and Wellman, M. P.: Latency arbitrage in fragmented markets: A strategic agent-based analysis, *Algorithmic Finance*, No. Preprint, pp. 1–25 (2016), http://content.iospress.com/articles/algorithmic-finance/af060

[Wang 13] Wang, C., Izumi, K., Mizuta, T., and Yoshimura, S.: Investigating the Impact of Trading Frequencies of Market Makers: a Multi-agent Simulation Approach, *SICE Journal of Control,Measument,and System Integration*, Vol. 6, No. 3, pp. 216–220 (2013), http://doi.org/10.9746/jcmsi.6.216

[Wang 17] Wang, Y. and Toriumi, F.: Analysis of group behavior bias in Financial Markets using artificial market, in *The Japanese Society for Artificial Intelligence Interest Group on Financial Infomatics*, Vol. 18 (2017), http://sigfin.org/SIG-FIN-018-21/

[Wellman 17] Wellman, M. P. and Wah, E.: Strategic Agent-Based Modeling of Financial Markets, *RSF*, Vol. 3, No. 1, pp. 104–119 (2017), http://www.rsfjournal.org/doi/abs/10.7758/RSF.2017.3.1.06

[Westerhoff 08] Westerhoff, F.: The use of agent-based financial market models to test the effectiveness of regulatory policies, *Jahrbucher Fur Nationalokonomie Und Statistik*, Vol. 228, No. 2, p. 195 (2008), http://dx.doi.org/10.1515/jbnst-2008-2-305

[Xiong 15] Xiong, Y., Yamada, T., and Terano, T.: Comparison of different market making strategies for high frequency traders, in *2015 Winter Simulation Conference (WSC)*, pp. 324–335 (2015), http://dx.doi.org/10.1109/WSC.2015.7408175

[Xiong 17] Xiong, X., Liang, J., Cui, Y., Zhang, W., and Zhang, Y.: Analysis of the Spot Market's T+1 Trading System Effects on the Stock Index Futures Market, *Eurasia Journal of Mathematics, Science and Technology Education*, Vol. 13, No. 12, pp. 7679–7693 (2017), http://dx.doi.org/10.12973/ejmste/77941

[Yagi 10] Yagi, I., Mizuta, T., and Izumi, K.: A Study on the Effectiveness of Short-selling Regulation using Artificial Markets, *Evolutionary and Institutional Economics Review*, Vol. 7, No. 1, pp. 113–132 (2010), http://dx.doi.org/10.14441/eier.7.113

[Yagi 12] Yagi, I., Mizuta, T., and Izumi, K.: A study on the reversal mechanism for large stock price declines using artificial markets, in *Computational Intelligence for Financial Engineering Economics (CIFEr), 2012 IEEE Conference on*, pp. 1 –7 (2012), http://dx.doi.org/10.1109/CIFEr.2012.6327791

[Yagi 16] Yagi, I. and Mizuta, T.: Analysis of the Impact of Leveraged ETF Rebalancing Trades on the Underlying Asset Market Using Artificial Market Simulation, in *12th Artificial Economics Conference* (2016), http://ae2016.it/public/ae2016/files/ssc2016_Mizuta.pdf sildes: http://www.slideshare.net/mizutata/20160921

[Yagi 17] Yagi, I., Nozaki, A., and Mizuta, T.: Investigation of the rule for investment diversification at the time of a market crash using an artificial market simulation, *Evolutionary and Institutional Economics Review*, Vol. 14, No. 2, pp. 451–465 (2017), http://dx.doi.org/10.1007/s40844-017-0070-9

[Yeh 10] Yeh, C. and Yang, C.: Examining the effectiveness of price limits in an artificial stock market, *Journal of Economic Dynamics and Control*, Vol. 34, No. 10, pp. 2089–2108 (2010), http://dx.doi.org/10.1016/j.jedc.2010.05.015

[Zhang 16] Zhang, X., Ping, J., Zhu, T., Li, Y., and Xiong, X.: Are Price Limits Effective? An Examination of an Artificial Stock Market, *PloS one*, Vol. 11, No. 8, p. e0160406 (2016), http://dx.doi.org/10.1371/journal.pone.0160406

[Zhang 17] Zhang, J., McBurney, P., and Musial, K.: Convergence of trading strategies in continuous double auction markets with boundedly-rational networked traders, *Review of Quantitative Finance and Accounting*, pp. 1–52 (2017), http://dx.doi.org/10.1007/s11156-017-0631-3

[Zhou 17] Zhou, X. and Li, H.: Buying on Margin and Short Selling in an Artificial Double Auction Market, *Computational Economics* (2017), https://doi.org/10.1007/s10614-017-9722-4