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

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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, Chakraborti 11, 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], extension of trading hours [Miwa 18] 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, Mizuta 18], 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], market efficiency [Immonen 17, Pruna 16, Tsao 17], market impacts [Cui 12, Oesch 14, Bouchaud 18], trading volume and price distortion [Lespagnol 17], financial market crush [Yagi 12, Paddrik 12, Torii 15, Schmitt 16, Benhammada 17, Lucas 18, Agliari 18], market liquidities on the network of banks [Sakiyama 16], effects of insider traders [Fuchen 18], 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

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artificial market research projects in the 2000s. 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 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.

As Weisberg mentioned [Weisberg 12], "Modeling, (is) the indirect study of real-world systems via the construction and analysis of models." "Modeling is not always aimed at purely veridical representation. Rather, they worked hard to identify the features of these systems that were most salient to their investigations." Therefore, under different phenomena to focus on, good models are different. Thus, a model is good only for the purpose of study and may be not good for other purposes.

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.

After [Mizuta 13a] be published, [Nagumo 16, Nagumo 17] built a simple model and introduced general analytical solutions explaining moving speed of trading volume share in competing financial markets due to tick size differences. The general analytical solutions showed that share is shifted from a market with a larger tick size to a market with a smaller tick size, and that the size of share-shift is determined by difference between tick sizes, not ratio between tick sizes.

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, Mizuta 18] 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,

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

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.

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