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Instability of financial markets by optimizing investment strategies investigated by an agent-based model

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(1) Introduction

(2) Our Model

(3) Simulation Results

(4) Conclusion

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Hypothesis of optimizing investment strategies is criticized

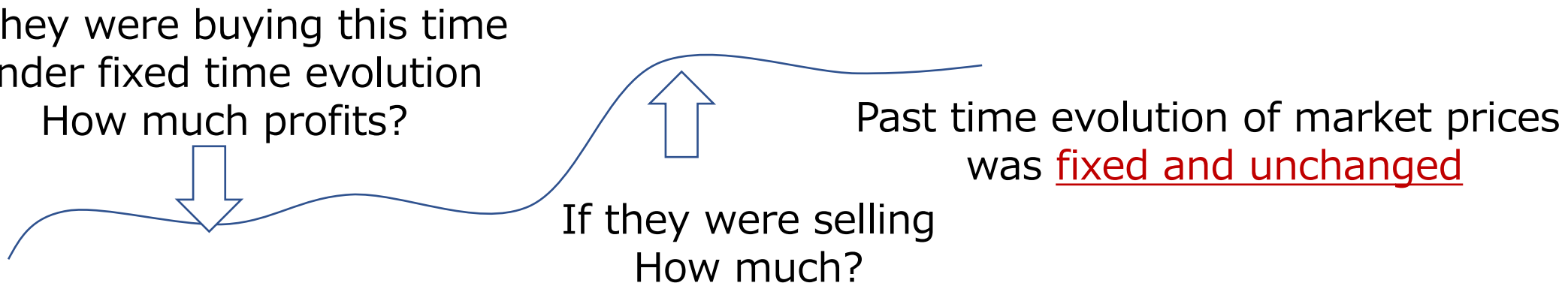
Most finance studies are discussed on the basis of several hypotheses. However, the hypotheses themselves are sometimes criticized.
The rational optimization of investors' investment strategies is also criticized.

* Investors themselves are not rational in the first place [Shiller 2003]
* Optimization is impossible due to the limitations of the investors' calculation ability [Shiozawa 2019]

・ **Impossibility of handling market impacts, where trades of investors can impact and change market prices, in "backtesting" also make optimization impossible.** Today's talk

"backtesting"

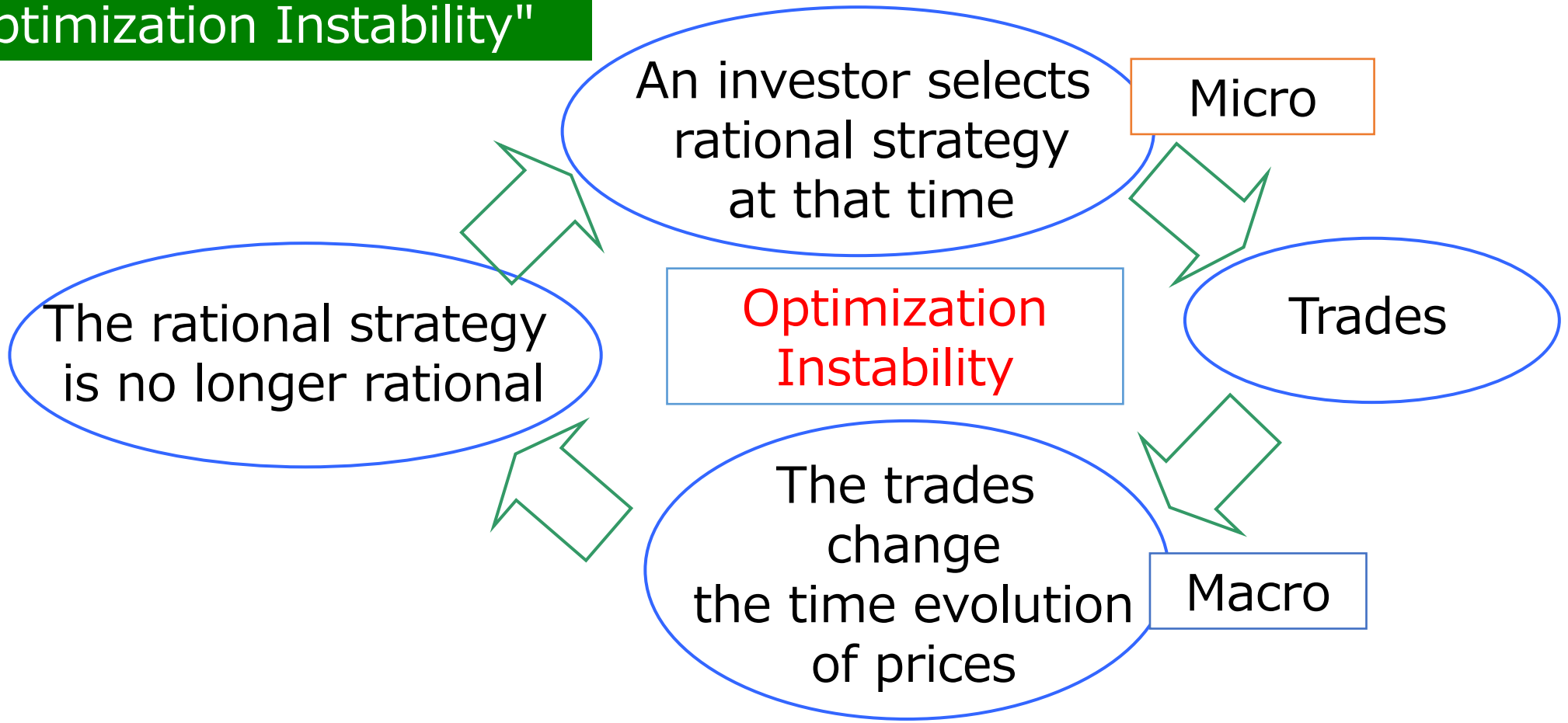
Investors profits are estimated if they were trading at past market prices.



In fact, there is no method to exactly estimate the market impact before trading.

Investors cannot estimate their earnings, including the effect of their market impacts.

“Optimization Instability"



Optimization instability causes not only market prices
but also the parameters of investment strategies to continually change

The optimization instability is one level higher than “non-equilibrium of market prices.”

Optimization Instability caused by this “micro-macro feedback loops”

(1)

Equilibrium of market prices

A parameter of investment strategy

Stably optimized

Market prices

Equilibrium (only noises)

(3)

Optimization instability

A parameter of investment strategy

Changing cyclically

Market prices

Non-equilibrium

(2)

Non-equilibrium of market prices

A parameter of investment strategy

Stably optimized

Market prices

Non-equilibrium

(4)

Optimization instability

A parameter of investment strategy

Changing irregularly and unexpectedly

Market prices

Non-equilibrium

An empirical study can not handle market impacts

We can not actually trade with large impacting.
An empirical study can not separate the causes of changing market prices whether by time evolution or by market impacts

An “artificial market model”, agent-based models for financial markets, can handle market impacts.

An artificial market model can fix other factors than market impacts.
Only an artificial market model can effectively handle micro-macro feedback loops.

No artificial market study optimized investment strategies in which an agent searches one optimized parameter in a whole simulation run in economics and financial studies, and no model determined whether only market impacts lead to optimization instability.

Therefore in this study,

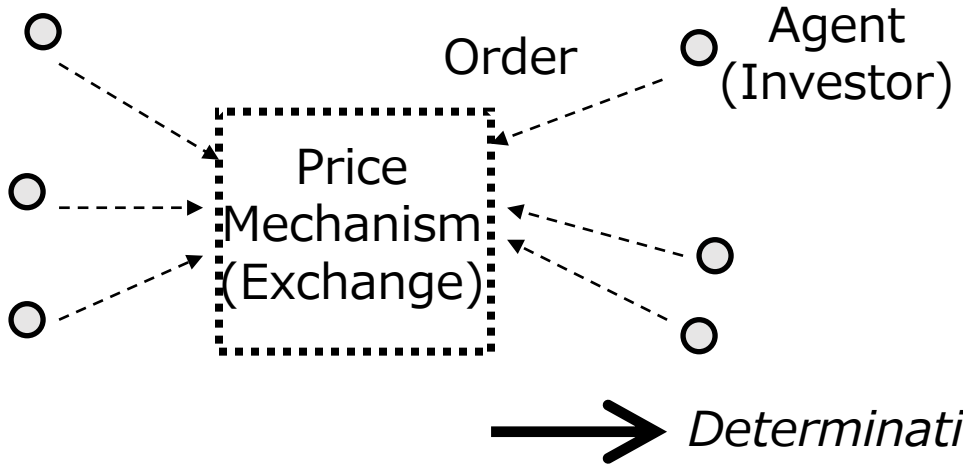
We built an artificial market model, agent-based models for financial markets, by adding technical analysis strategy agents (TAs), which search one optimized parameter in a whole simulation run, to the prior model of Mizuta[2016].
The TAs are a momentum TA (TA-m) and reversal TA (TA-r), and we investigated whether investors' inability to accurately estimate market impacts in their optimizations leads to optimization instability

An artificial market model = an agent-based model for a financial market

Virtual and Artificial financial Market built on Computers

Models Include

Agents (Artificial Investors)
+
Price Mechanism (Artificial Exchange)



Each Agent determines an order by some rules, Price Mechanism gather agents orders and determines Market Price

Complete Computer Simulation needing NO Empirical Data

- ✓ can discuss on the mechanism between the micro-macro feedback
- ✓ can be conducted to investigate situations that have never occurred in actual financial markets
- ✓ **can effectively handling micro-macro feedback loops**

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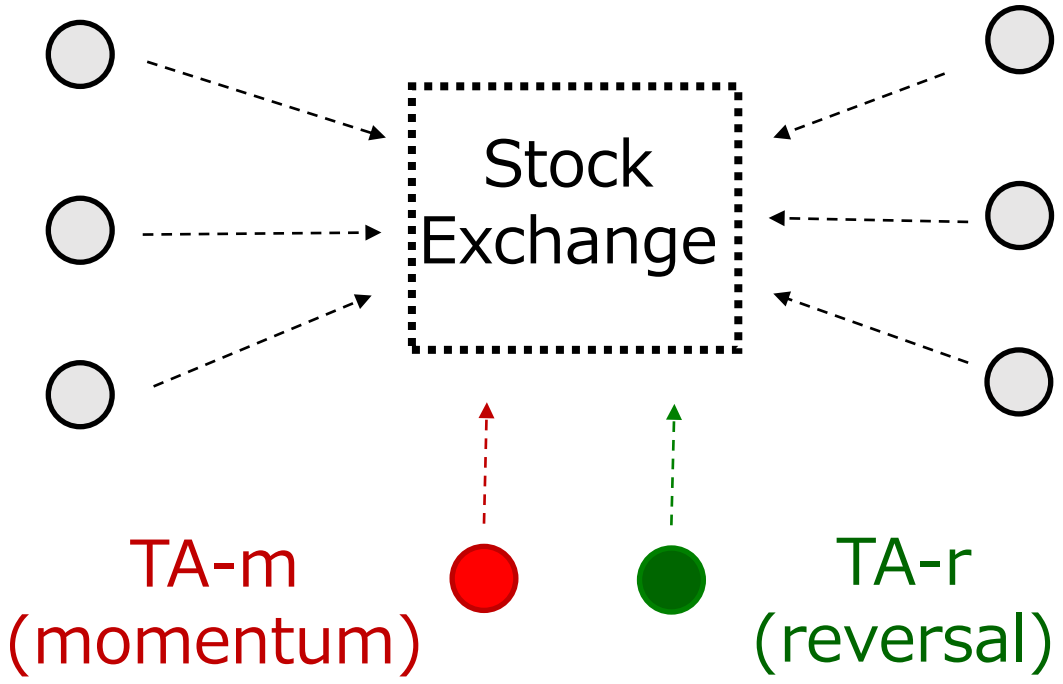
My Model

Normal Agents (NAs) exist 1000 agents

To replicate the nature of price formation in actual financial markets, I introduced the NA to model a general investor.



Two TAs exist one TA-m and one TA-r

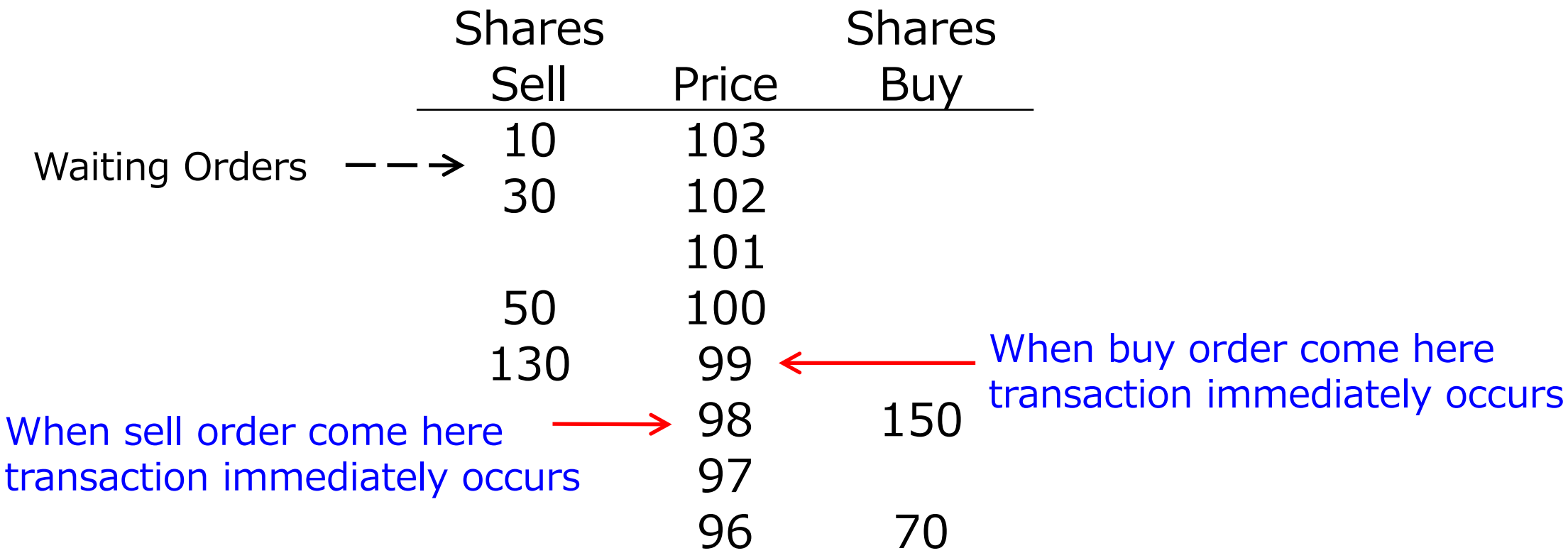
In this study, the artificial market model was built by adding the two Tas to the prior model of Mizuta et al[2016]

Two TAs (technical analysis strategy agents) search their one optimized parameter to a whole simulation run

(TAs details will be showed later)

Stock Exchange (Price Mechanism)

continuous double auction



Multiple buyers and sellers compete to buy and sell stocks in the market, and transactions can occur at any time whenever an offer to buy and an offer to sell match.

Normal Agents (NAs)

1000 agents

j: agent number ordering in number order
t: tick time

This term is needed To replicate stylized facts

Technical

Expected Return of each NA

$$r_{e,j}^{t} = \frac{1}{\sum_i w_{i,j}} \left(w_{1,j} \log \frac{P_f}{P^{t-1}} + w_{2,j} \log \frac{P^{t-1}}{P^{t-\tau_j}} + w_{3,j} \varepsilon_j^t \right)$$

Parameters for agents

$w_{i,j}$ and τ_j

Random of Uniform Distribution

$w_{i,j}$ i=1,3: 0～1
i=2: 0～100

τ_j 0～10000

Fundamental

P_f Fundamental Price
10000 = constant

P^t Market Price at t

This term is needed to prevent the prices go out far away

noise

ε_j^t
Random of Normal Distribution
Average=0
σ=3%

To keep agents varied
To keep simulation runs stably

Expected Price of each NA

$$P^t{}_{e,j} = P^t \exp(r^t{}_{e,j})$$

Fundamental Strategy

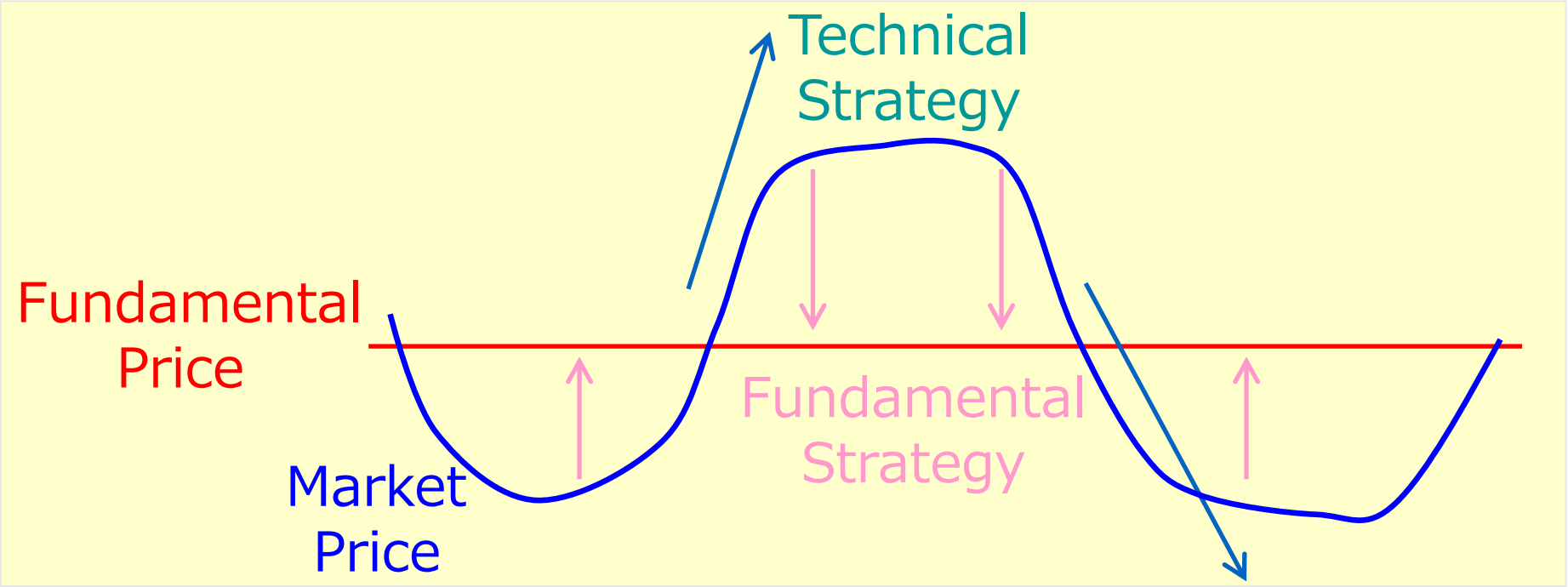
Fundamental Price > Market Price -> Expect + return

Fundamental Price < Market Price -> Expect - return

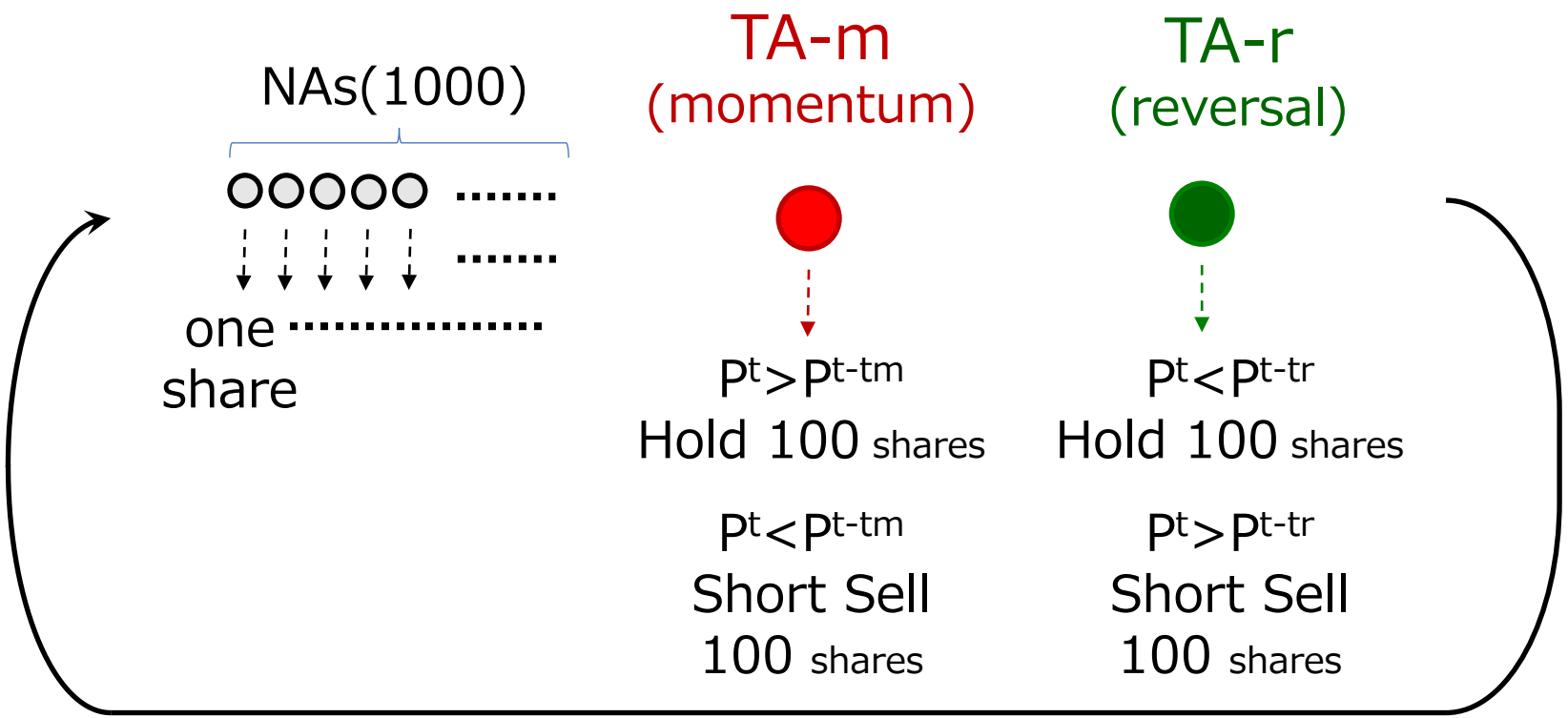
Technical Strategy (Historical Return)

Historical Return > 0 -> Expect + return

Historical Return < 0 -> Expect - return

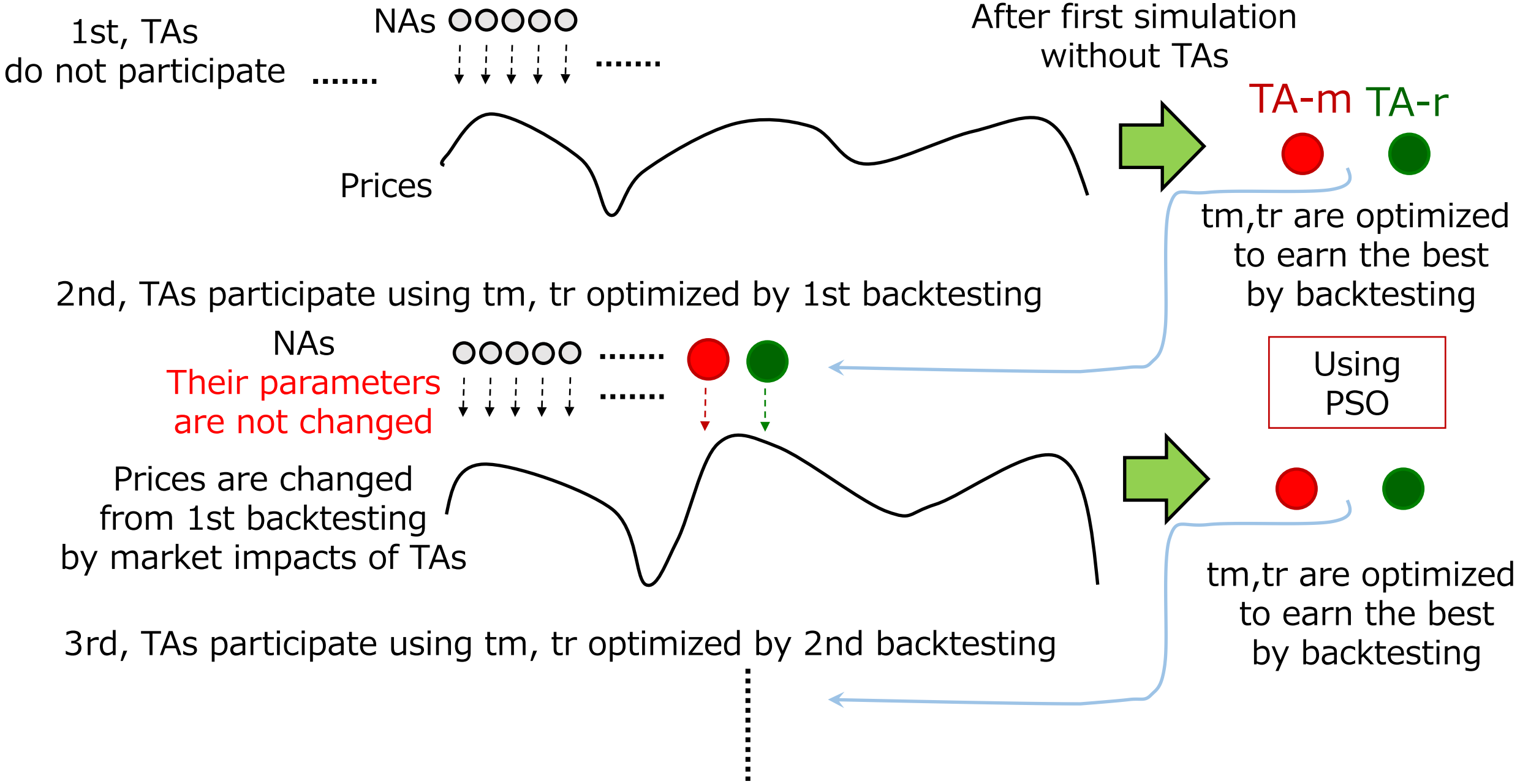


TAs: Placing orders



After the 1000 NA places an order, the TA-m and TA-r place orders in this order when the following conditions are satisfied. tm,tr are optimized to earn the best by backtesting

TAs: optimizing the parameters



“Fixed” normal agents

1000 agents

j: agent number ordering in number order
t: tick time

Here are changed
by changing time evolution
of market prices

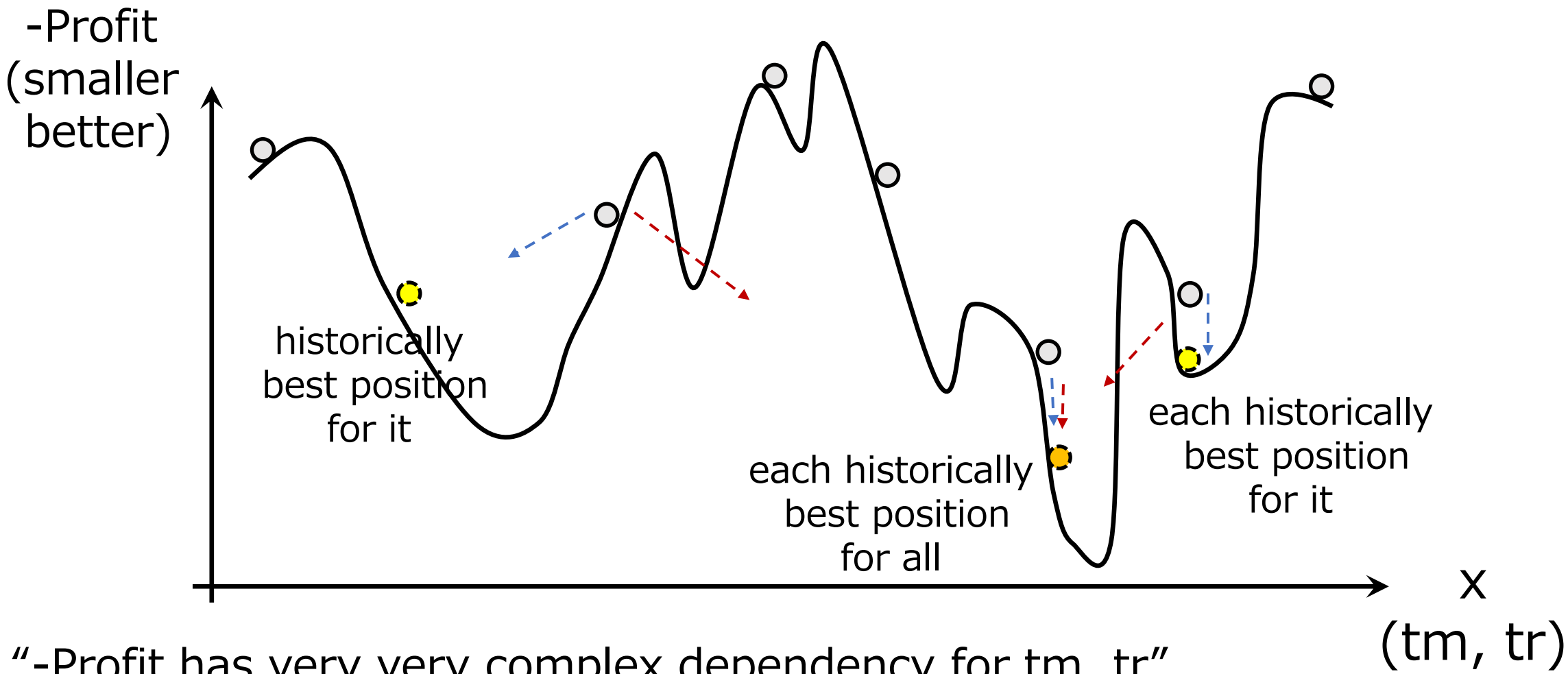
Expected Return
of each NA

$$r_{e,j}^{t} = \frac{1}{\sum_i w_{i,j}} \left(w_{1,j} \log \frac{P_f}{P^{t-1}} + w_{2,j} \log \frac{P^{t-1}}{P^{t-\tau_j}} + w_{3,j} \varepsilon_j^t \right)$$

Here are fixed

Including (ε_j^t), the parameters of normal agents are fixed.
However, their trades are changed
by changing time evolution of market prices.

PSO(Particle Swarm Optimization)



"-Profit has very very complex dependency for tm, tr"
-> Finding the minimum "-Profit" is very difficult -> PSO is good solution
In the PSO there are many "particles", and they are pull to both
their each historically best position and their all historically best.
Thanks to "many" particles, they are rarely trapped into local solution.

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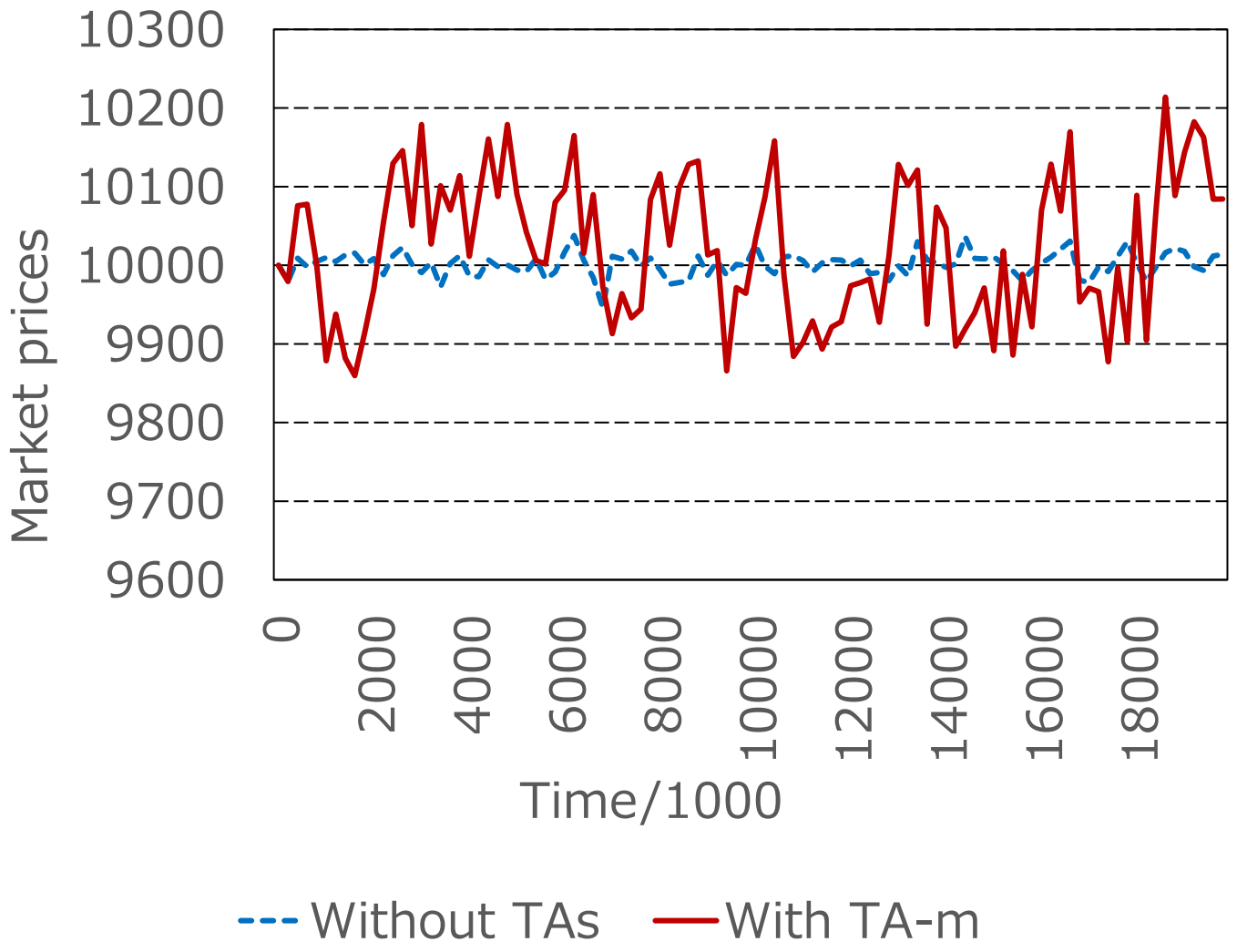
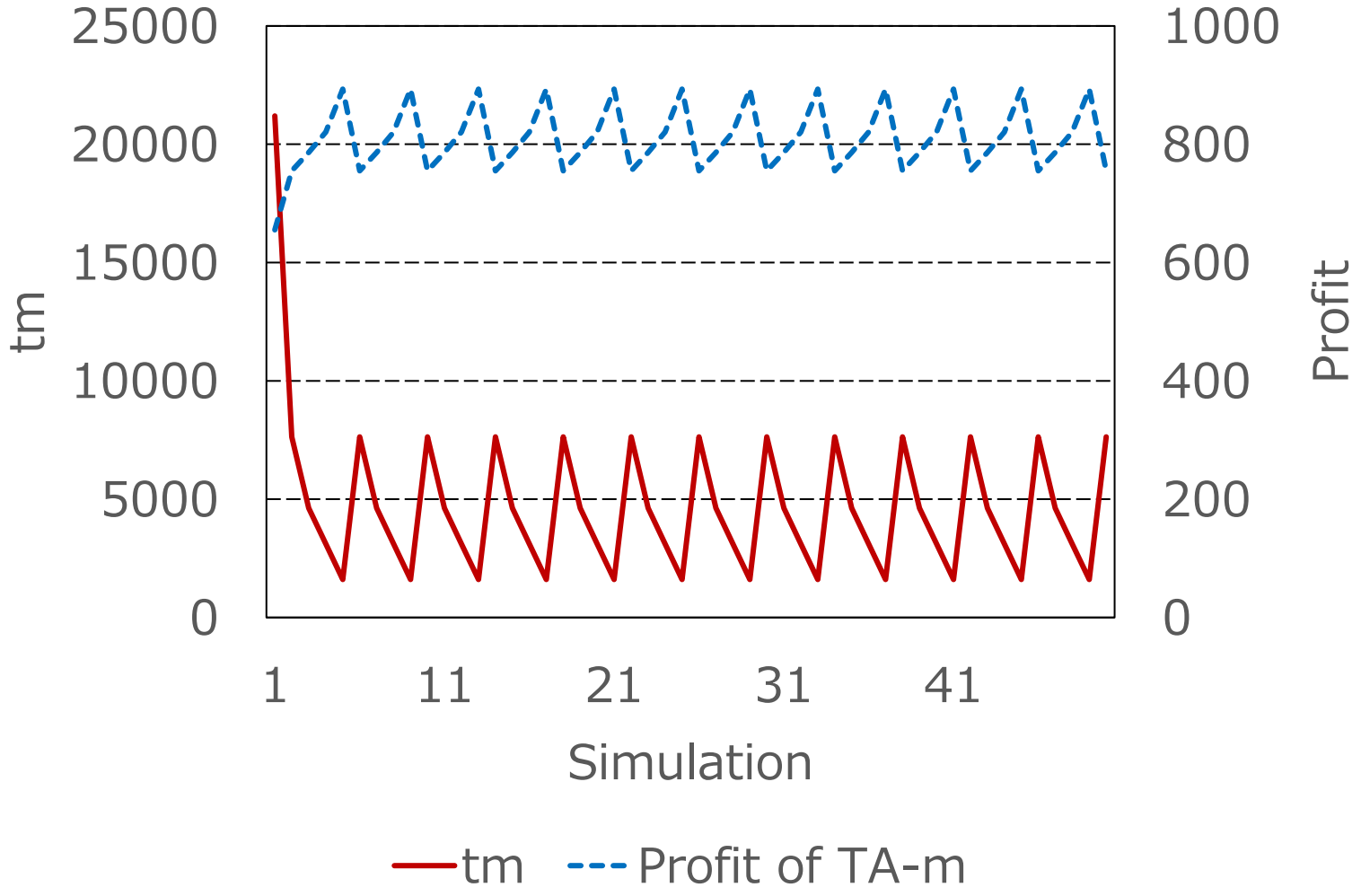
Time evolution of the prices with TA-m and without it

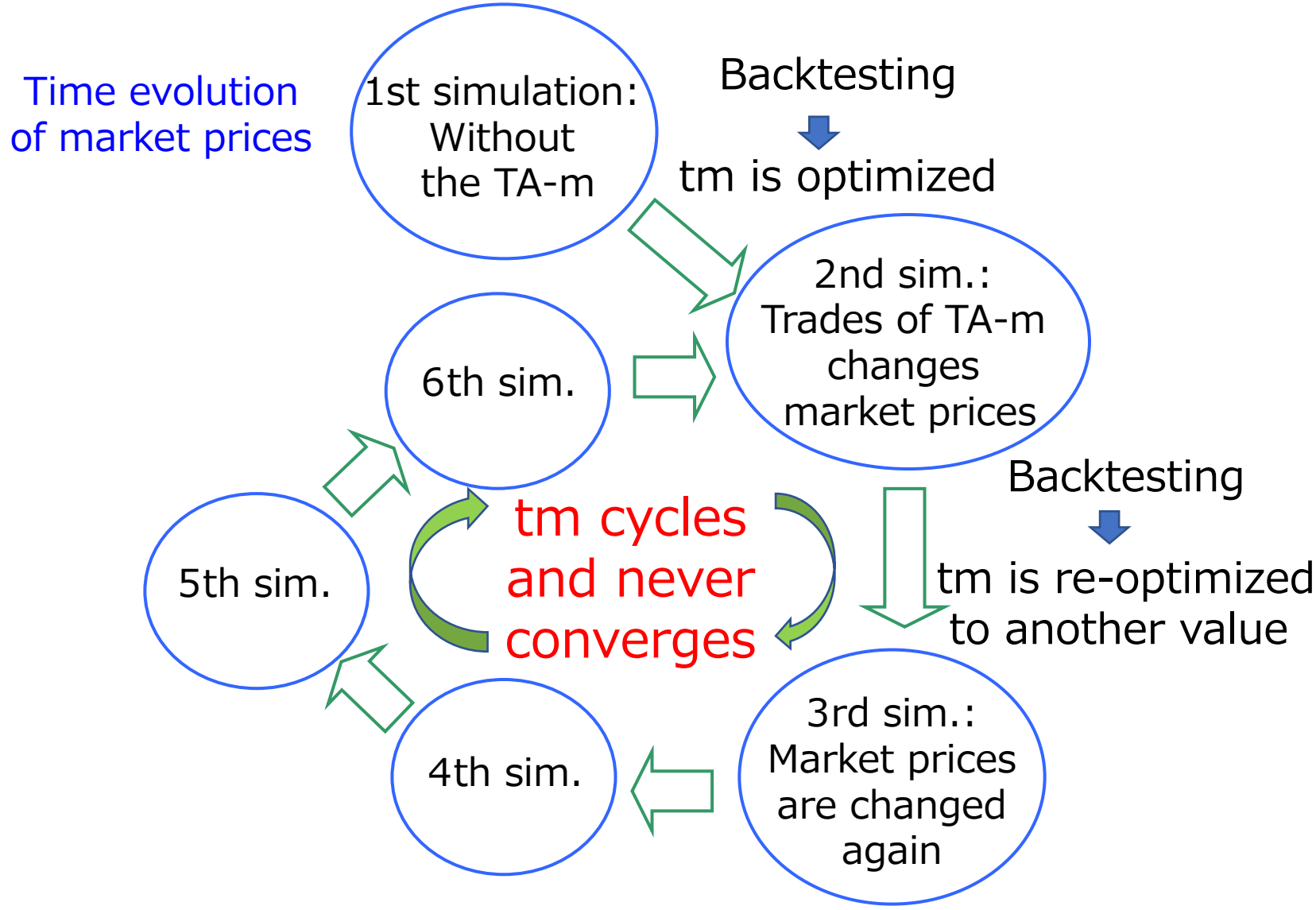


The existence of the TA-m enlarged the price variation.

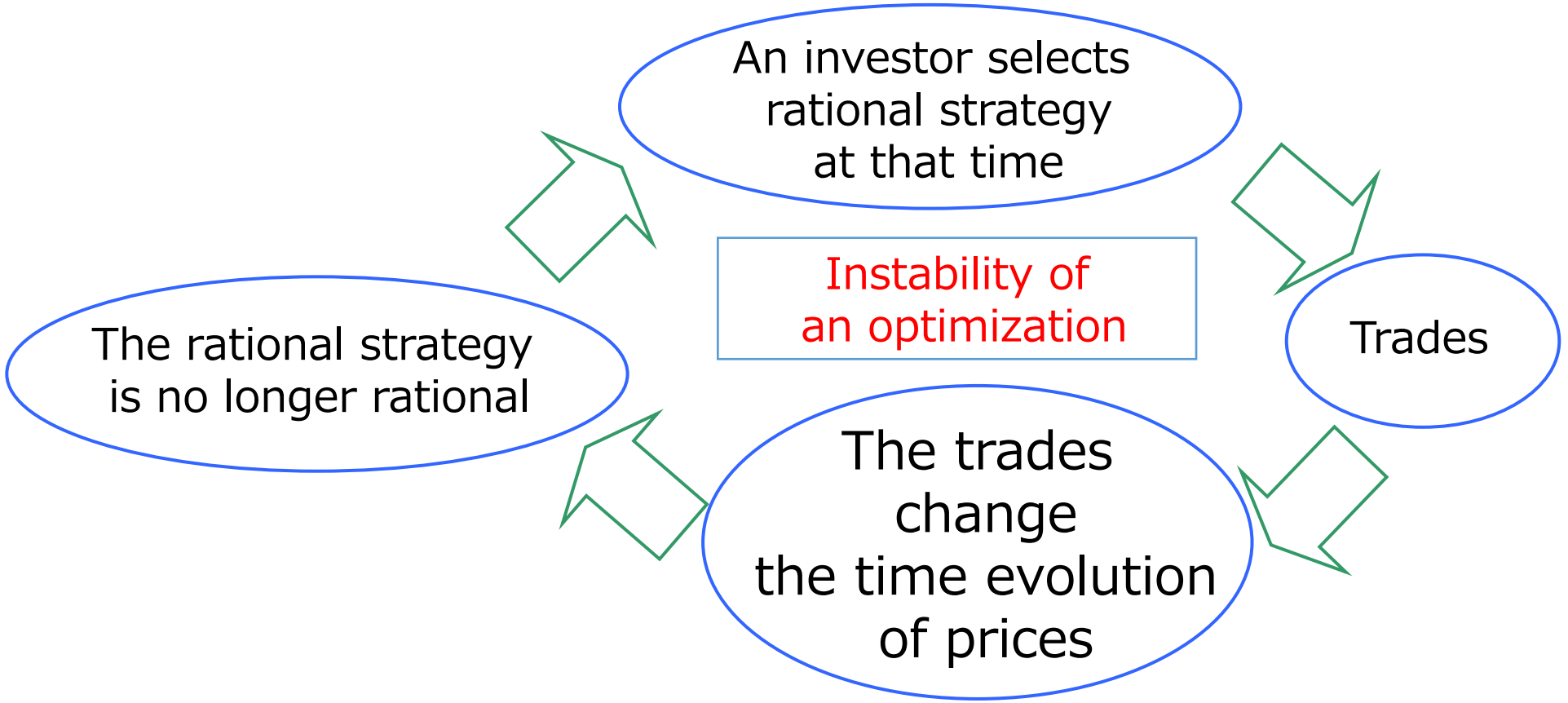
tm and profits of the TA-m with TA-m



tm never converged to a specific value but changed in a cyclic manner.
The optimization of TA-m strategy is unstable.



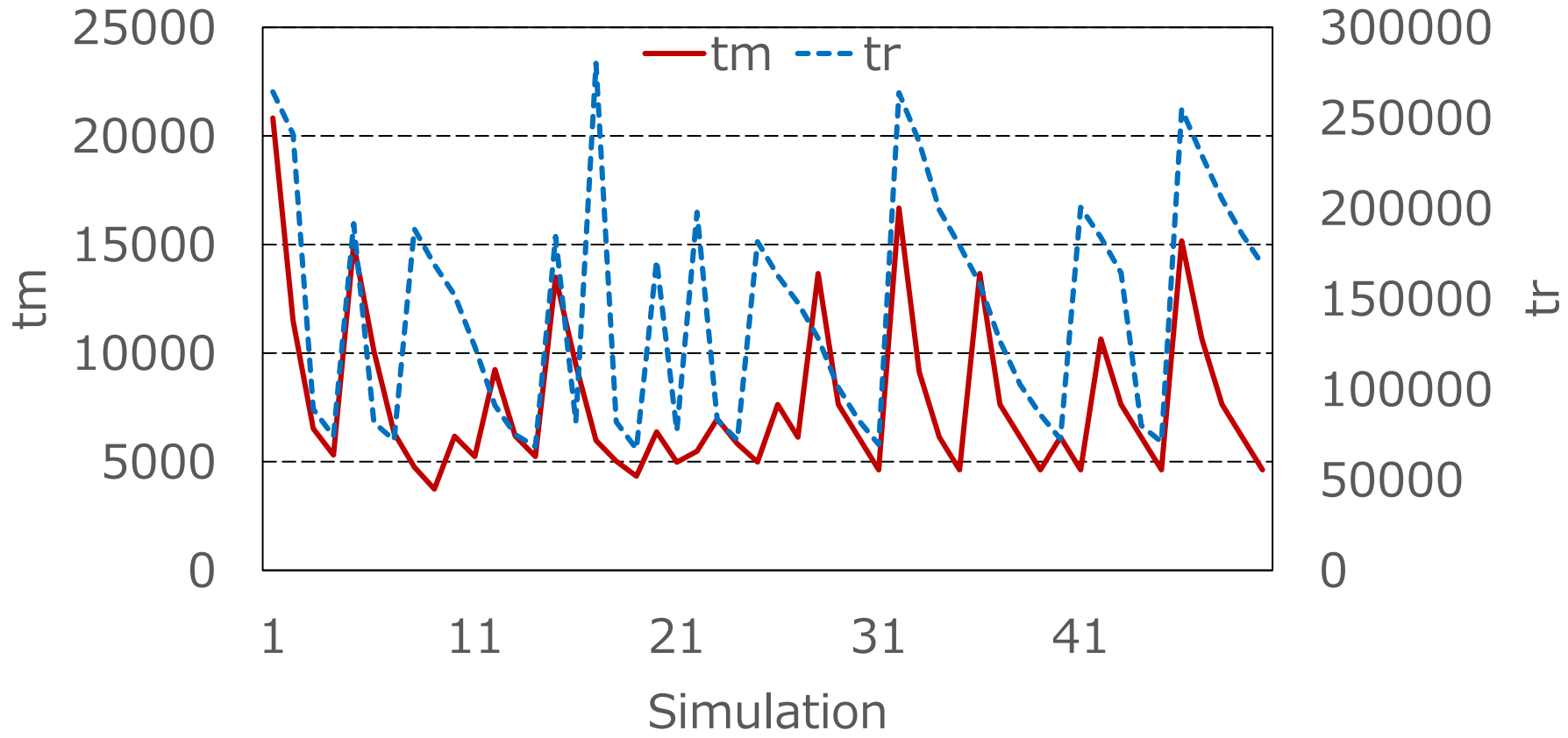
Strategies of traders never reach the equilibrium, and the optimized parameters of strategies are never fixed in time.



Even if all other traders are fixed, only one investor optimizing his/her strategy using backtesting leads to time evolution of market prices becoming unstable.

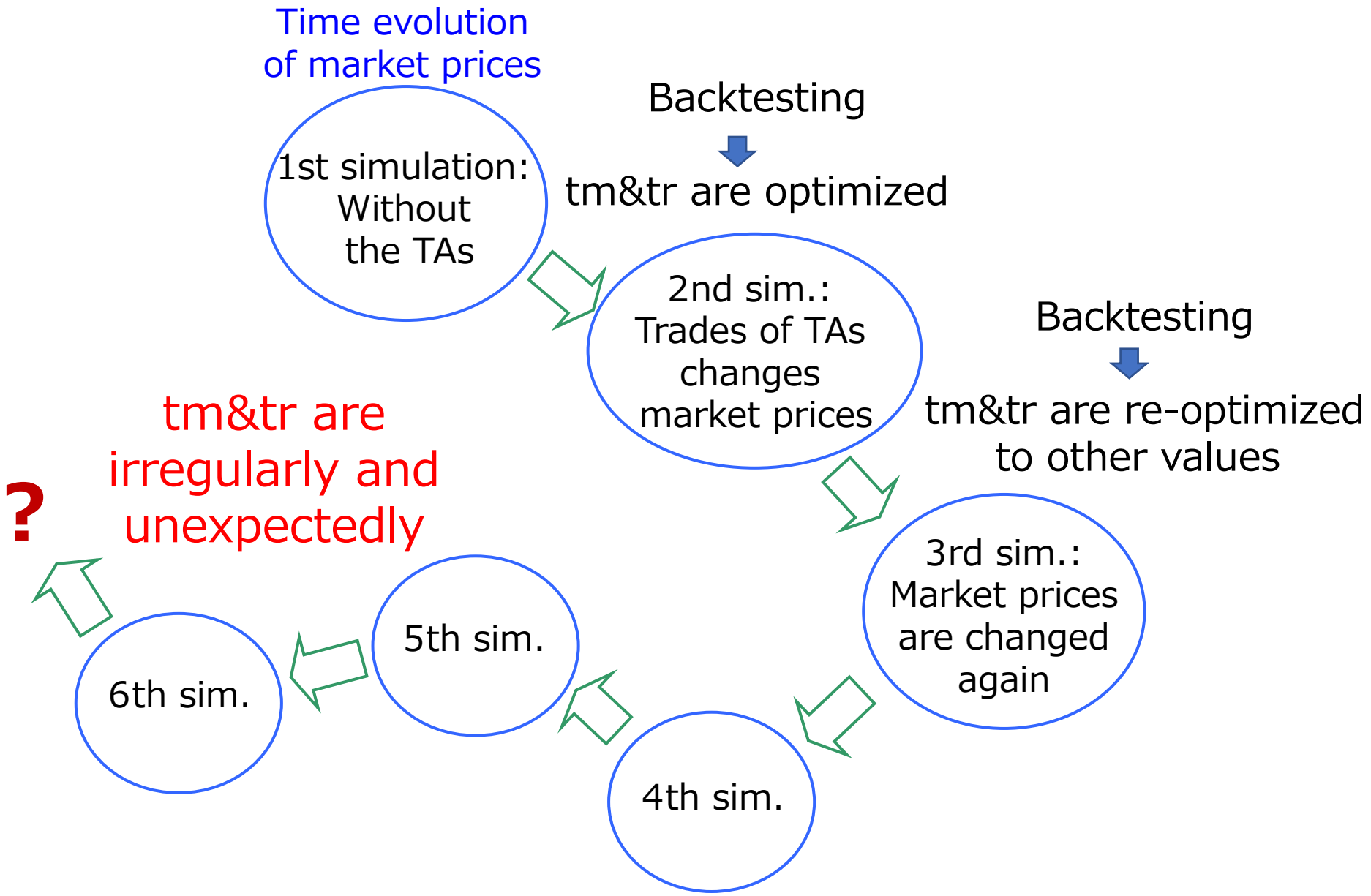
Financial markets are essentially unstable, and naturally, investment strategies are not able to be fixed. The reason is that even when one investor selects a rational strategy at that time, it changes the time evolution of prices, it becomes no longer rational, another strategy becomes rational, and the process repeats.

tm, tr with both the TA-m and TA-r



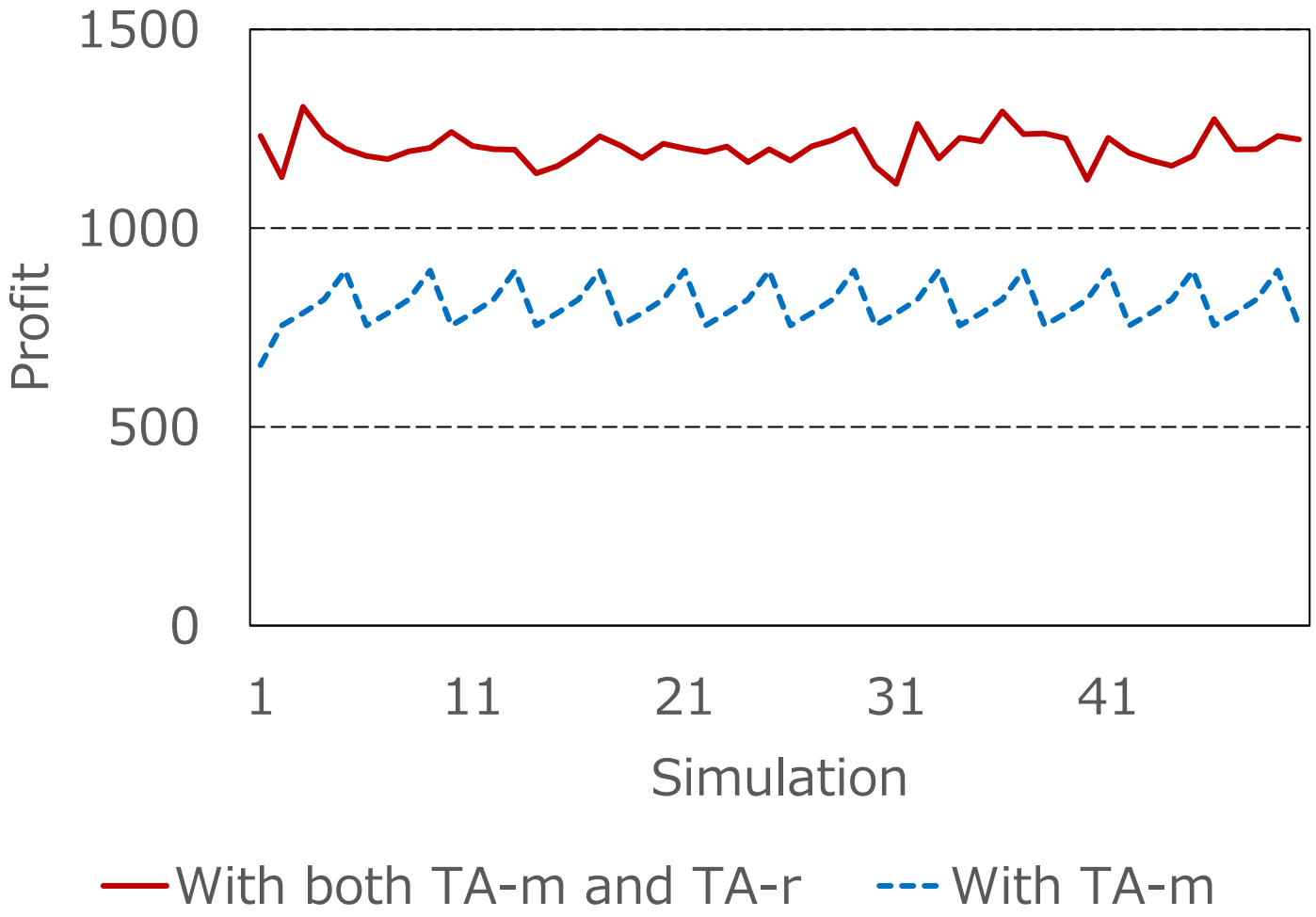
The changes of tm, tr were irregular and unexpected

The time evolution of market prices produced by investment strategies having such unstable parameters is highly unlikely to be predicted and have stable laws written by equations. This nature makes us suspect that financial markets include the principle of natural uniformity and indicates the difficulty of building an equation model explaining the time evolution of prices.



Both tm and tr do not return to certain historical values,
so the changes of tm, tr are irregular and unexpected.

Profits of TA-m with only TA-m and with both TA-m TA-r



TA-m earned more than that without TA-r. A profit of one strategy is not stolen by the another strategy, but both strategies increase their profits.

The result is consistent with [Mizuta 2021]

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Conclusion (1/2)

- ✓ In this study, we built an artificial market model by adding technical analysis strategy agents (TAs), which search one optimized parameter in a whole simulation run, to the prior model of [mizuta 2016]. The TAs are a momentum TA (TA-m) and reversal TA (TA-r), and we investigated whether investors' inability to accurately estimate market impacts in their optimizations leads to optimization instability.
- ✓ When both the TA-m and TA-r exist, the parameters of investment strategies were changing irregularly and unexpectedly. This means that even if all other traders are fixed, only one investor optimizing his/her strategy using backtesting leads to the time evolution of market prices becoming unstable. Financial markets are essentially unstable, and naturally, investment strategies are not able to be fixed. The reason is that even when one investor selects a rational strategy at that time, it changes the time evolution of prices, it becomes no longer rational, another strategy becomes rational, and the process repeats.

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Conclusion (2/2)

- ✓ Optimization instability is one level higher than ``non-equilibrium of market prices.'' Therefore, the time evolution of market prices produced by investment strategies having such unstable parameters is highly unlikely to be predicted and have stable laws written by equations. This nature makes us suspect that financial markets include the principle of natural uniformity and indicates the difficulty of building an equation model explaining the time evolution of prices.

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Reference

- [Mizuta 2016] 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, https://doi.org/10.1002/isaf.1374

- [Mizuta 2021] Mizuta, T., “Do new investment strategies take existing strategies' returns -An investigation into agent-based models-”, BESC 2021, October 29 to 31, 2021 https://doi.org/10.1109/BESC53957.2021.9635097

Review of an agent-based model for designing a financial market

Mizuta (2020) An agent-based model for designing a financial market that works well, CIFEr 2020

arXiv https://arxiv.org/abs/1906.06000

Slide: https://mizutatakanobu.com/2021kyushu.pdf

YouTube: https://youtu.be/rmlb72ykmlE

Citing many previous studies

Mizuta (2016) A Brief Review of Recent Artificial Market Simulation Studies for Financial Market Regulations And/Or Rules, SSRN Working Paper Series

https://ssrn.com/abstract=2710495

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Appendix

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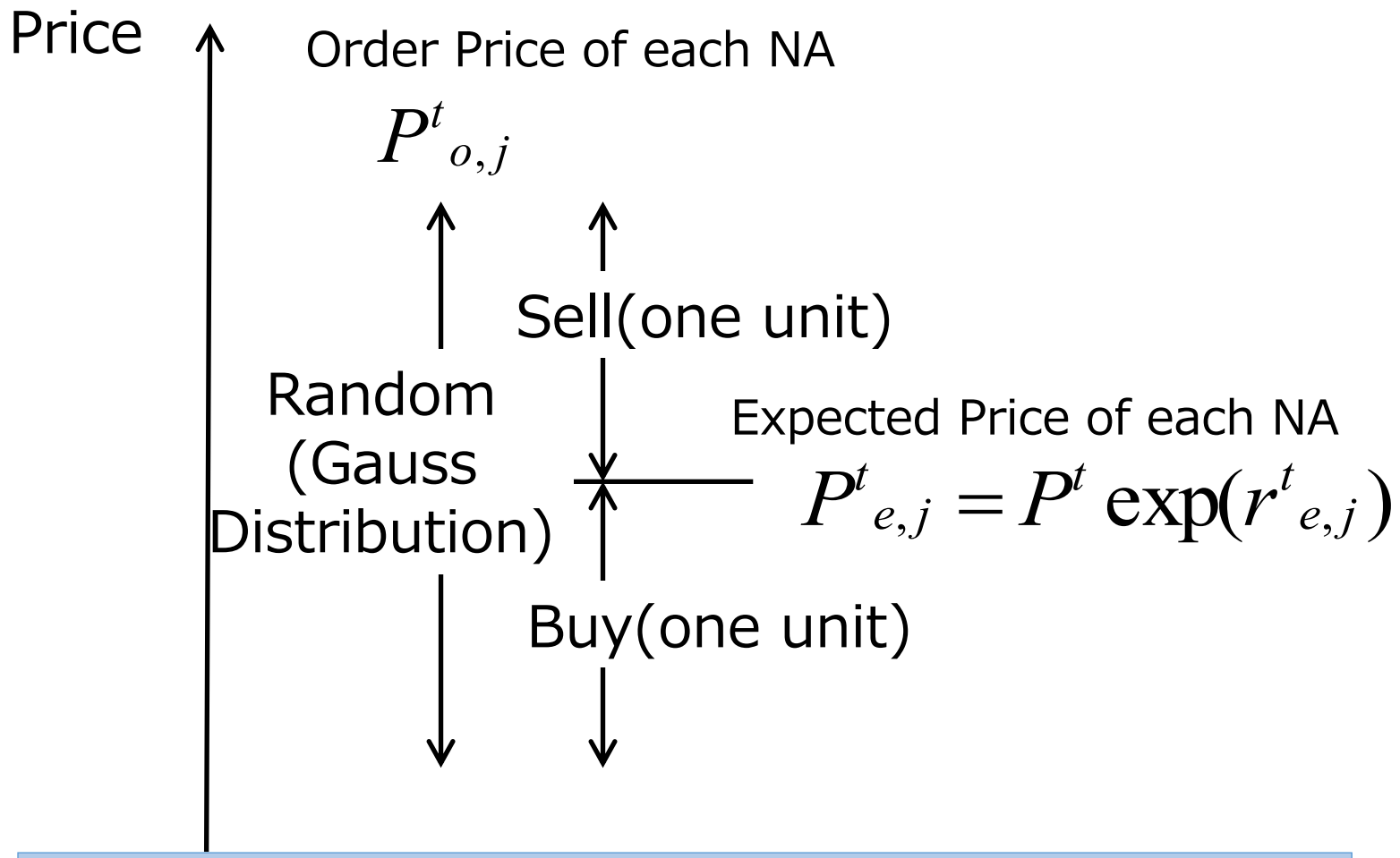
Order Price and Buy or Sell



To replicate many waiting limit orders,
order price is scattered around expected price

NA places one **buy** order when order price > expected price
NA places one **sell** order when order price < expected price

Verification: Stylized Facts

The purpose of simulation is understanding the reasons and mechanism, not replicating ALL Stylized Facts

The simplicity of the model is very important because unnecessary replication of macro phenomena leads to models that are overfitted and too complex. Such models prevent understanding and discovery of mechanisms affecting price formation because of the increase in related factors.

Many empirical studies, e.g., Sewell 2006 have shown that both stylized facts (fat-tail and volatility-clustering) exist statistically in almost all financial markets.
Conversely, they also have shown that only the fat-tail and volatility-clustering are stable for any asset and in any period because financial markets are generally unstable.

Fat-tail 1 to 100

kurtosis of price returns is positive

Volatility-clustering 0 to 0.2

square returns have a positive auto-correlation

The magnitudes of these values are unstable and vary greatly depending on the asset and/or period.

For the above reasons, an artificial market model should replicate these values as significantly positive and within a reasonable range as I mentioned. It is not essential for the model to replicate specific values of stylized facts because the values of these facts are unstable in actual financial markets.

Stylized Facts

Table 1 Statistics without arbitrage agents

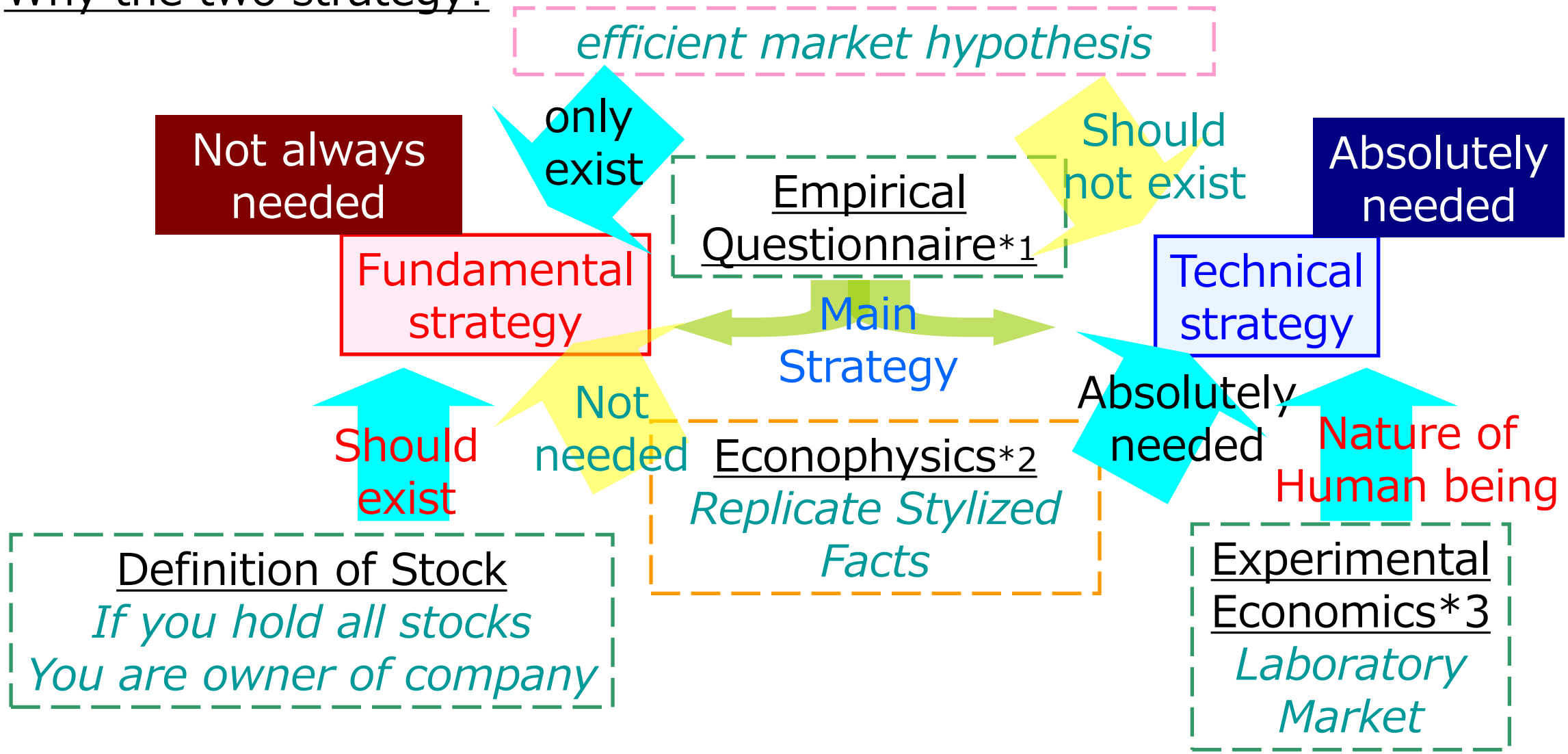
trading	execution rate	32.3%
	cancel rate	26.1%
	number of trades / 1 day	6467
standard deviations	for 1 tick	0.0512%
	for 1 day (20000 ticks)	0.562%
	kurtosis	1.42
autocorrelation coefficient for square return	lag	
	1	0.225
	2	0.138
	3	0.106
	4	0.087
	5	0.075

The model of Chiarella (2002) is very simple but replicates long-term statistical characteristics observed in actual financial markets: a fat tail and volatility clustering.

In contrast, Mizuta (2013) replicates high-frequency micro structures, such as execution rates, cancel rates, and one-tick volatility, that cannot be replicated with the model of Chiarella (2002).

The simplicity of the model is very important for this study, because unnecessary replication of macro phenomena leads to models that are overfitted and too complex. Such models prevent understanding and discovery of mechanisms affecting price formation because of the increase in related factors.

Why the two strategy?



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Yamamoto, R. (2021): Predictor Choice, Investor Types, and the Price Impact of Trades on the Tokyo Stock Exchange, Computational Economics
https://arxiv.org/abs/1906.06000

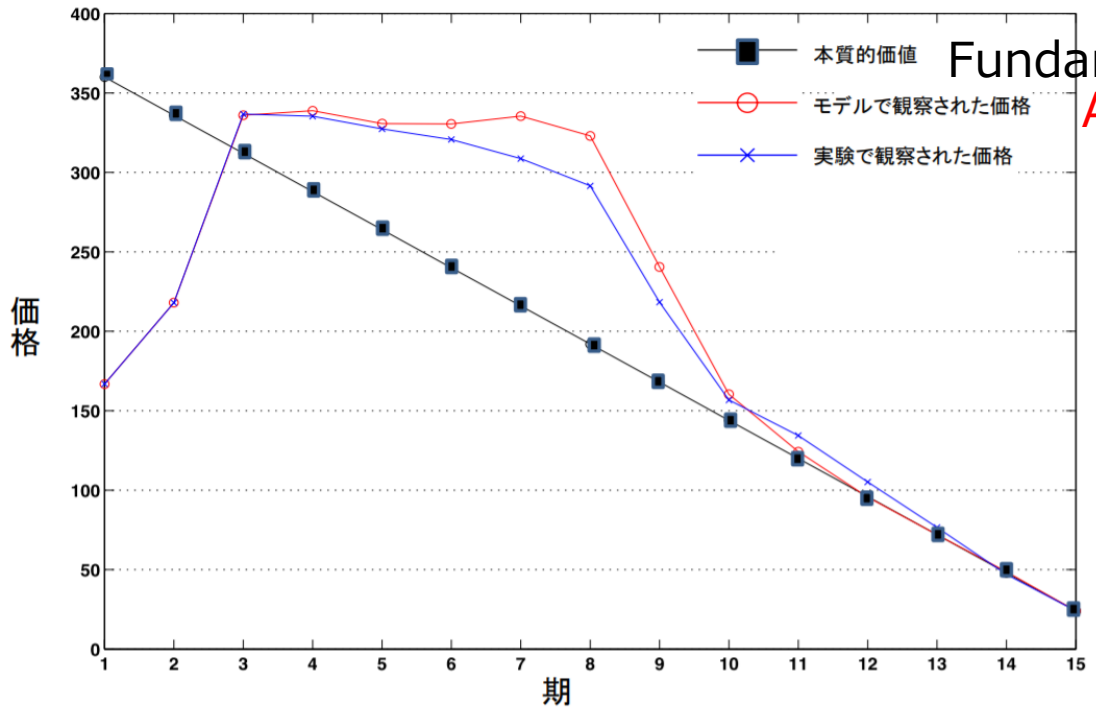
*2 Lux, T. and Marchesi, M.(1999) Scaling and criticality in a stochastic multi-agent model of a financial market, Nature

*3 Haruvy and Noussair (2006): The Effect of Short Selling on Bubbles and Crashes in Experimental Spot Asset Markets
https://doi.org/10.1111/j.1540-6261.2006.00868.x

Laboratory Market vs. Artificial Market

Sorry, the figure from Japanese book
https://www.coronasha.co.jp/np/isbn/9784339028164/

実験結果とモデルシミュレーションの結果の対比



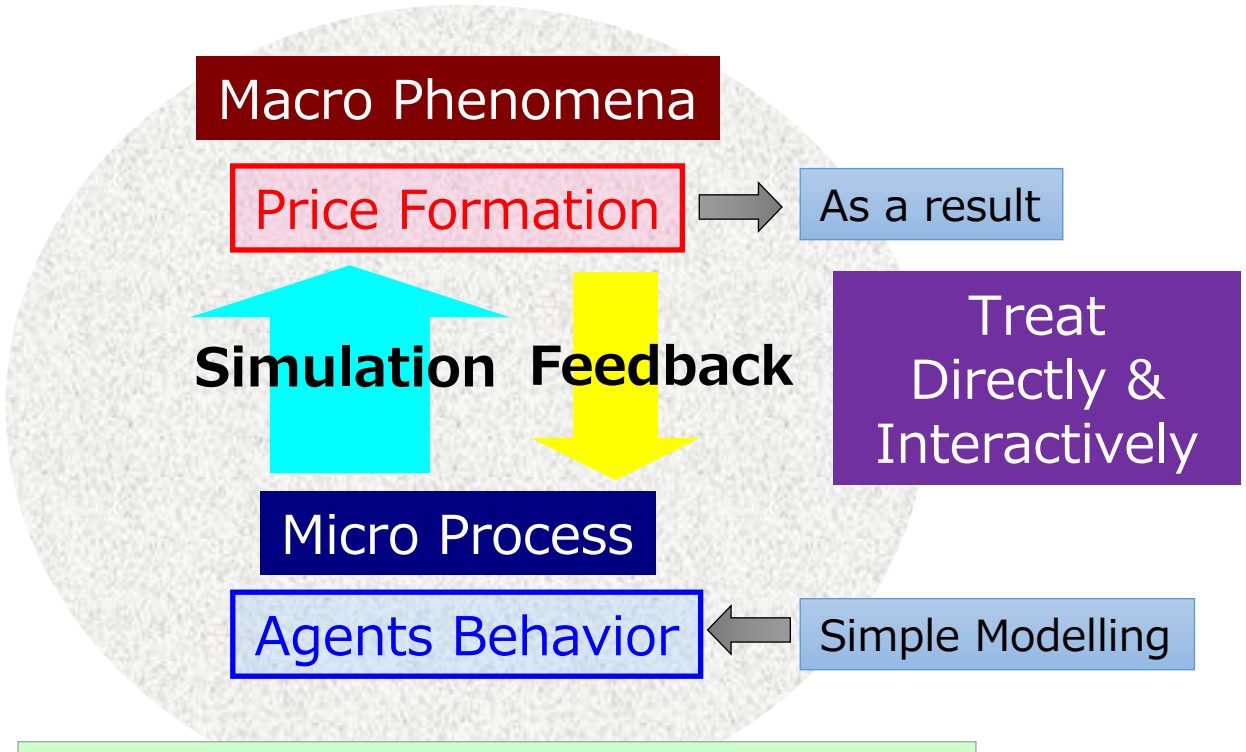
Fundamental Price
Artificial Market
Laboratory Market

Source: Haruvy and Noussair (2006)
のモデルと実験データを基に作成

Haruvy and Noussair (2006): The Effect of Short Selling on Bubbles and Crashes in Experimental Spot Asset Markets
https://doi.org/10.1111/j.1540-6261.2006.00868.x

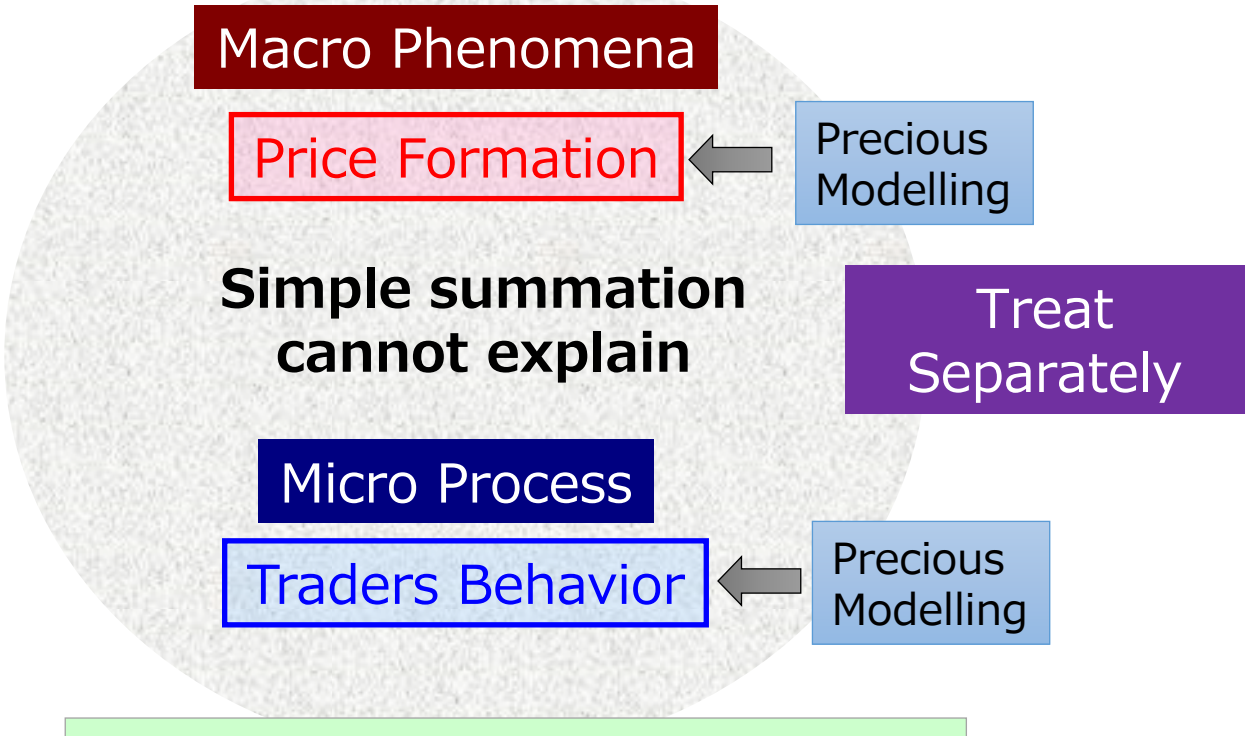
Parameter fitting of the artificial market model including fundamental and technical strategies leads to similar results with the laboratory market. This means that both strategies are needed to replicate the laboratory market, and they may also be needed to replicate real markets.

An Agent-Based Model



can directly treat and clearly explain the interactions

A mathematical model
An empirical study



cannot directly treat nor clearly explain the interactions