2020 IEEE Symposium Series on Computational Intelligence (SSCI)
on Computational Intelligence for Financial Engineering
and Economics (CIFEr) http://www.ieeessci2020.org/

Paper ID: #30

An agent-based model for designing a financial market that works well

Takanobu Mizuta SPARX Asset Management Co., Ltd.

Mail: mizutata[at]gmail.com
HP: https://mizutatakanobu.com

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

You can download this presentation material from
https://mizutatakanobu.com/2020CIFErb.pdf

This presentation showed a philosophy of an agent-based artificial market model.
Why models are needed? How models should be? In the first place, what is a model?
We should understand what is a model deeper for healthy discussion using a model.
I will try to clear up a common misunderstanding for a model.
After the discussion, I will review the case, investigating tick size reduction using a model.

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

(2) Suitable complexity, advantages and disadvantages

(3) Case study: tick size reduction

(4) Conclusion

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

(2) Suitable complexity, advantages and disadvantages

(3) Case study: tick size reduction

(4) Conclusion

Importance and difficulty of market design

People have been able to develop advanced economies by cooperating to exchange goods for money

Creation of any industry requires “investment” to first purchase or build tools to make goods

Financial Market enables smooth investment

Financial Market Creates Better Goods Better Service

Two Extreme Opinions

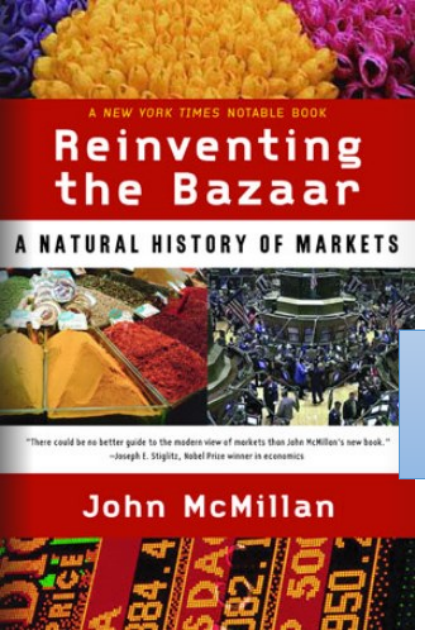
No regulation is Best? ⟷ Destroy a Society?

Both is Wrong

“A market works well only if it is well designed”

Proper rules and regulations are required

(By the economist John McMillan, who used game theory to investigate many markets)



John McMillan, 2002
https://wwnorton.com/books/Reinventing-the-Bazaar/

"A market works well only if it is well designed"

Market design determines whether a market works well or badly

⇔

A market is a highly complex system. It is at least as complex as the systems studied by physicists and biologists

Very important for Developing economy

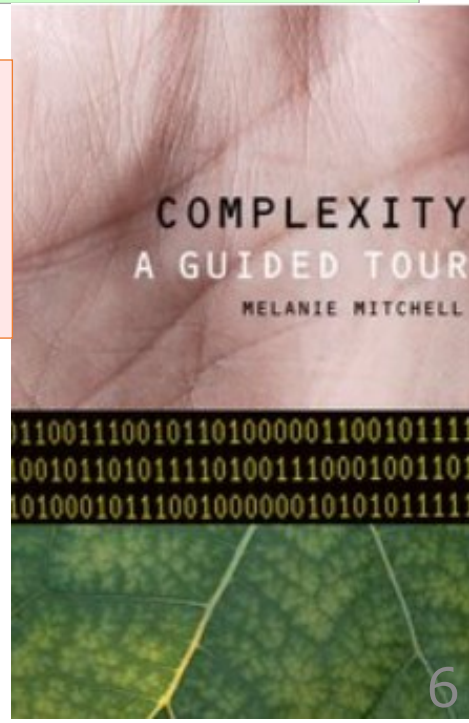
Very difficult and complex system

"Economies are complex systems in which the simple, microscopic components consist of people buying and selling goods, and the collective behavior is the complex, hard-to-predict behavior of markets as a whole, such as fluctuations in stock prices"

Changing detailed rules, even ones that seem trivial, sometimes causes unexpected large impacts and side effects.

both God and the devil are in the details

Designing a market well is very important for developing an advanced economy, but not easy.



Melanie Mitchell, 2009
https://global.oup.com/academic/product/complexity-9780195124415

Agent-Based Model succeeded to explain Social Complex Systems other than Financial Market

For examples,

- Making Evacuation Route of new building for Fire and/or Terror
- Investigating for effects of building new roadway to traffic jam
- Discussing how spread COVID-19

and so on

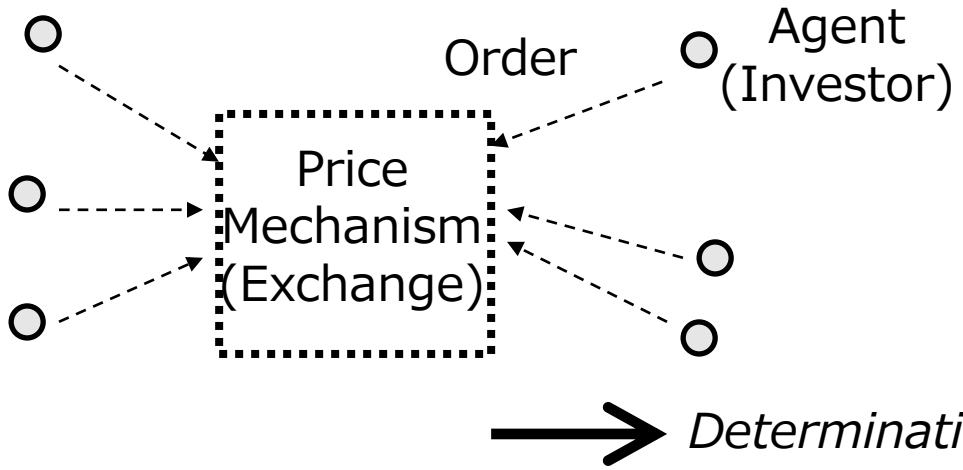
There are many many studies succeeded explain the phenomena of social complex systems

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 be conducted to isolate the direct effect of changing rules

NATURE/SCIENCE articles argued Importance of Simulations

- Farmer and Foley (2009) **NATURE**, Vol. 460, No. 7256, pp. 685-686.
  https://www.nature.com/articles/460685a

  In today's high-tech age, one naturally assumes that US President Barack Obama's economic team and its international counterparts are using sophisticated quantitative computer models to guide us out of the current economic crisis. They are not. There is a better way: agent-based models.

- Battiston et al. (2016) **SCIENCE**, Vol. 351, Issue 6275, pp. 818-819.
  http://science.sciencemag.org/content/351/6275/818

  Traditional economic theory could not explain, much less predict, the near collapse of the financial system and its long-lasting effects on the global economy. Since the 2008 crisis, there has been increasing interest in using ideas from complexity theory to make sense of economic and financial markets.

These articles argued that

Traditional economic theory could not explain, much less predict, the near collapse of the financial system

Agent-Based Model is needed

Criticism to Standard Economic Model and arguing needs of Agent-Based Model

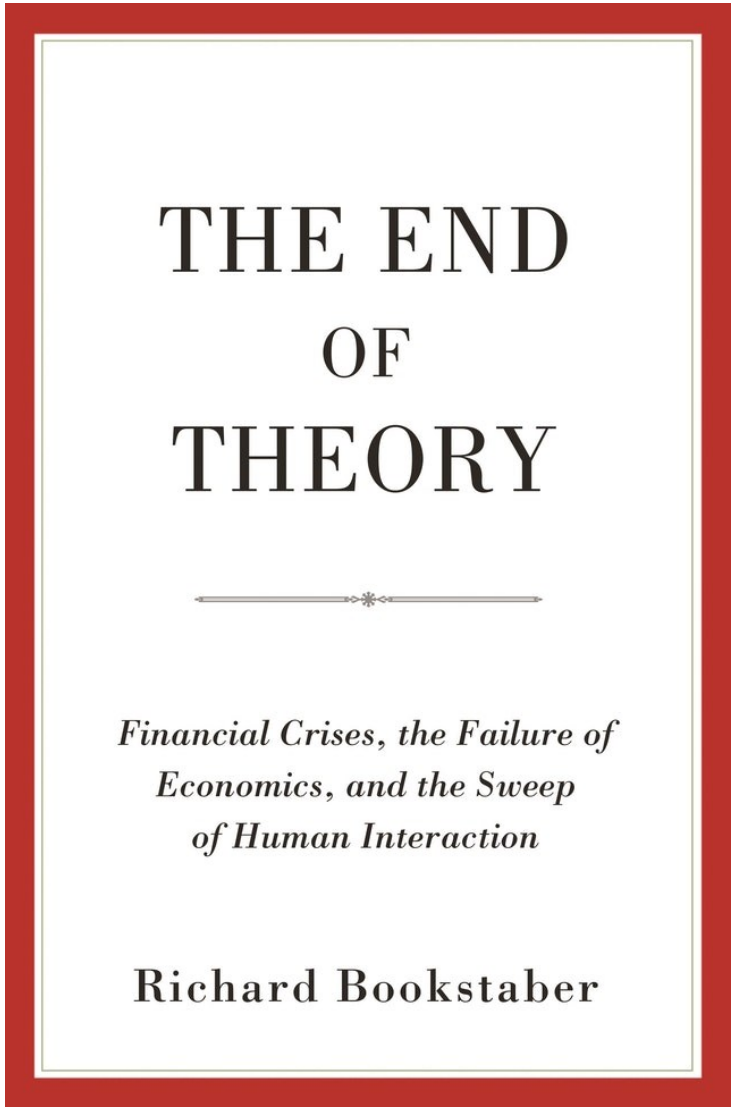
Richard Bookstaber

Expert of risk management at Investment Banks and Hedge Funds

Famous for The author of “A Demon of Our Own Design” is noted for its forecasting of the financial crisis of 2008

Standard Economic Model did not prevent Financial Crises of 2008. An Agent-Based Model will prevent the Crises.

Arguing importance of using Agent-Based Model when we discuss how prevent the Financial Crises



Richard Bookstaber, 2017
https://press.princeton.edu/books/hardcover/9780691169019/the-end-of-theory

Practical Persons have began to use Agent-Based Model to solve Urgent Real Problem

Regulators, Central Bankers, Stock Exchanges

日本取引所グループ
東京証券取引所
大阪取引所
日本取引所自主規制法人
日本証券クリアリング機構

JPX Working Papers Series

JPX(parent com of Tokyo Stock Exchange) shows Working Papers,
10 papers of all 34 are Agent-Based Studies
Reduction of Tick Size, Frequently Batch Auction,
Suitable Latency of Exchange System, and so on

https://www.jpx.co.jp/english/corporate/research-study/working-paper/index.html

So many other Examples,

Working Paper by Bank of Japan

Toshiyuki Sakiyama and Tetsuya Yamada, Market Liquidity and Systemic Risk in Government Bond Markets: A Network Analysis and Agent-Based Model Approach
https://www.imes.boj.or.jp/research/abstracts/english/16-E-13.html

Project by EU

Integrated Macro-Financial Modelling for Robust Policy Design Work Package 7: Bridging agent-based and dynamic-stochastic-general-equilibrium modelling approaches for building policy-focused macro financial models https://cordis.europa.eu/project/id/612796/reporting

My review

Takanobu Mizuta, 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

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

(2) Suitable complexity, advantages and disadvantages

(3) Case study: tick size reduction

(4) Conclusion

An agent-based model explaining a complex system

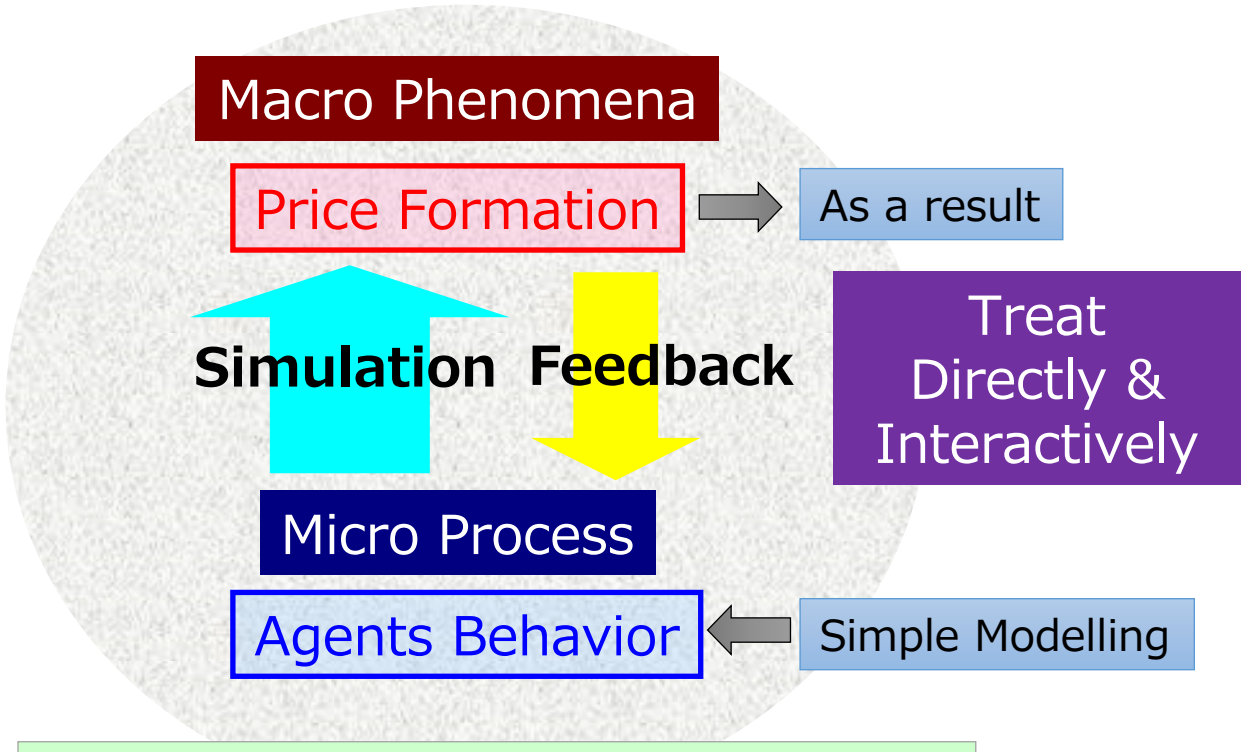
A financial market is highly complex system where a simple summation of micro processes (trader behaviors) never explains macro phenomena (price formation).

Separately investigating macro phenomena and micro processes unclearly explains complex systems where macro phenomena and micro processes interact.

A mathematical model An empirical study	cannot directly treat nor clearly explain the interactions
An Agent-Based Model	can directly treat and clearly explain the interactions

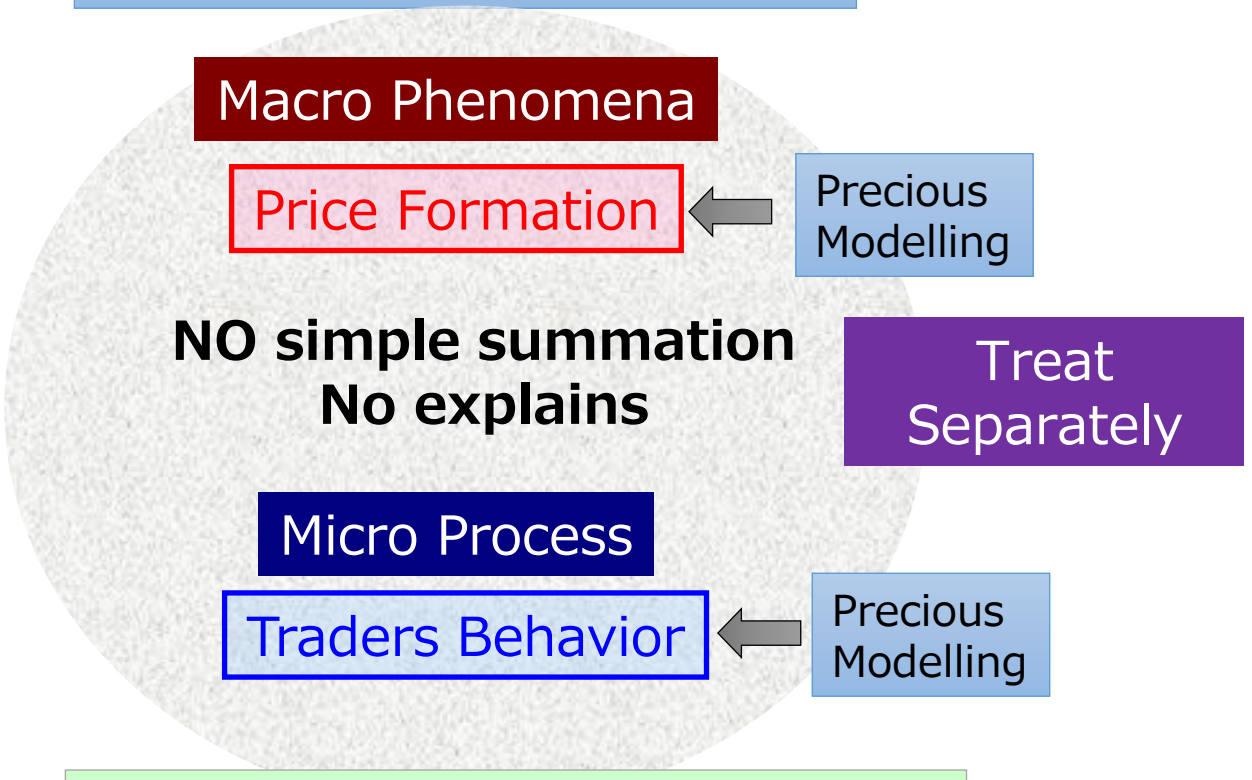
Because…

An Agent-Based Model



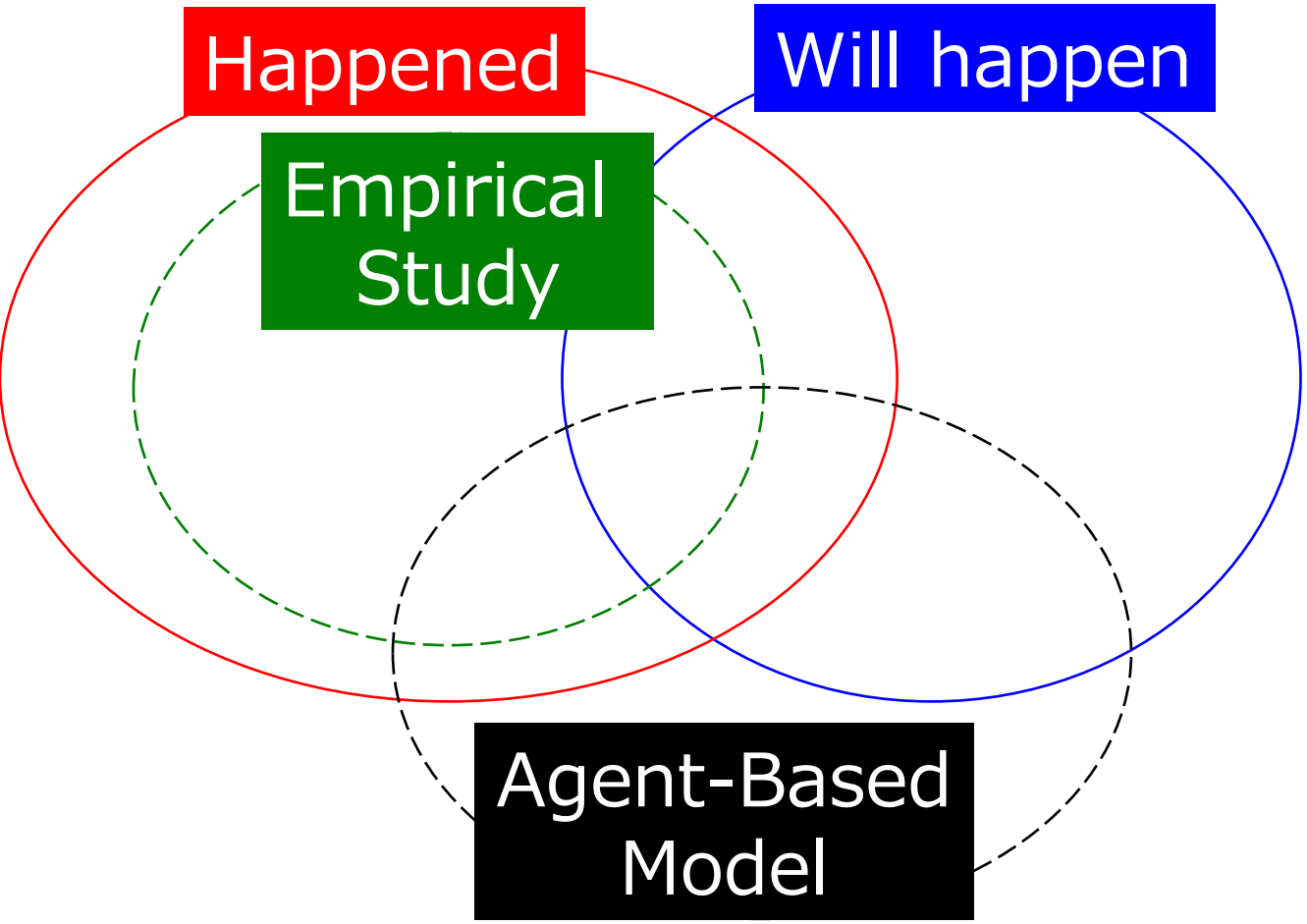
can directly treat and clearly explain the interactions

A mathematical model An empirical study



cannot directly treat nor clearly explain the interactions

Advantages and Disadvantages of Agent-Based Model

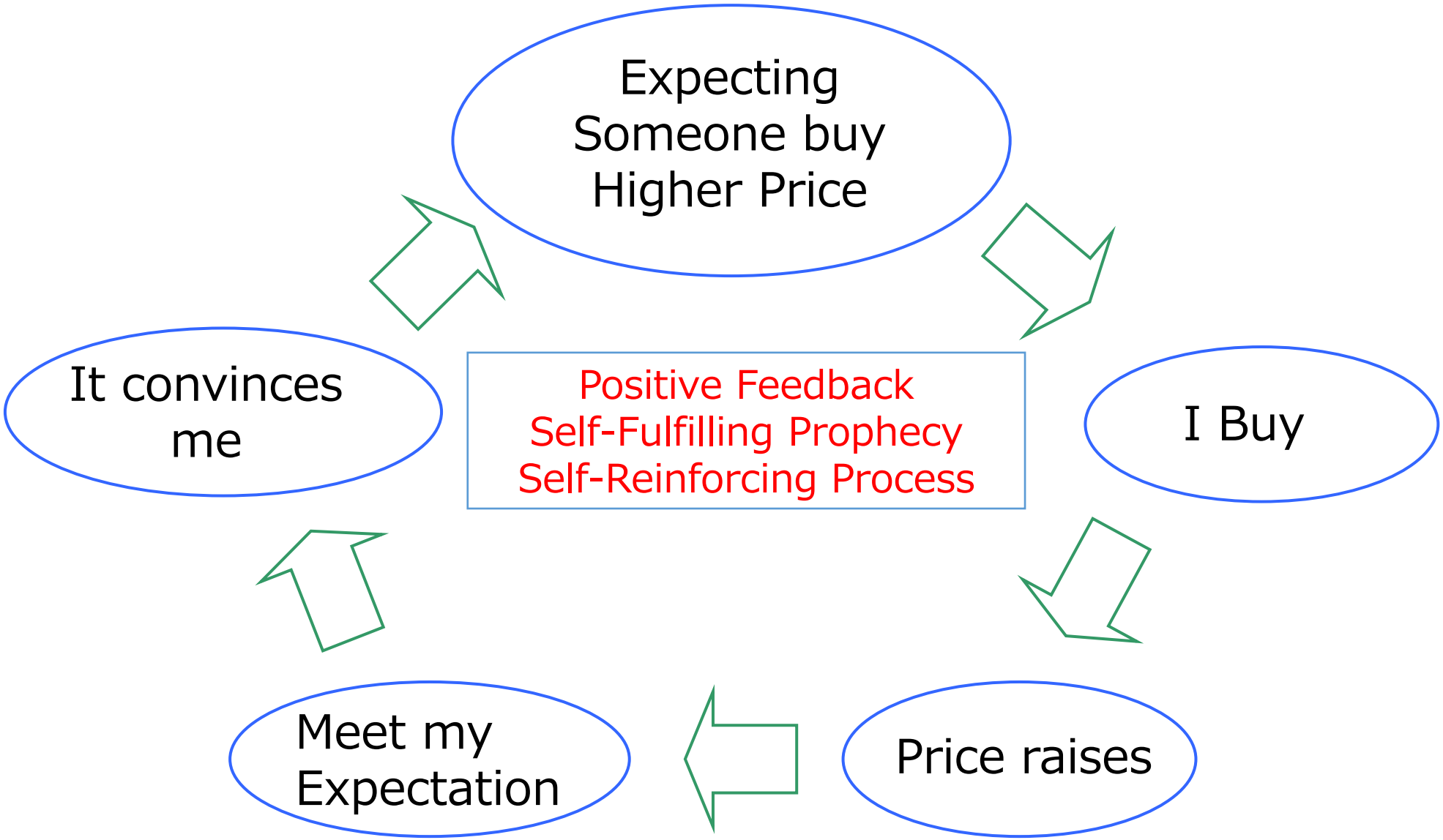


Outputs of an empirical study are included in the area that has happened in a real financial market. The advantage of an empirical study is outputs exclude the all area not happening in the past or future. The disadvantage, however, is outputs exclude any area happening in the future.

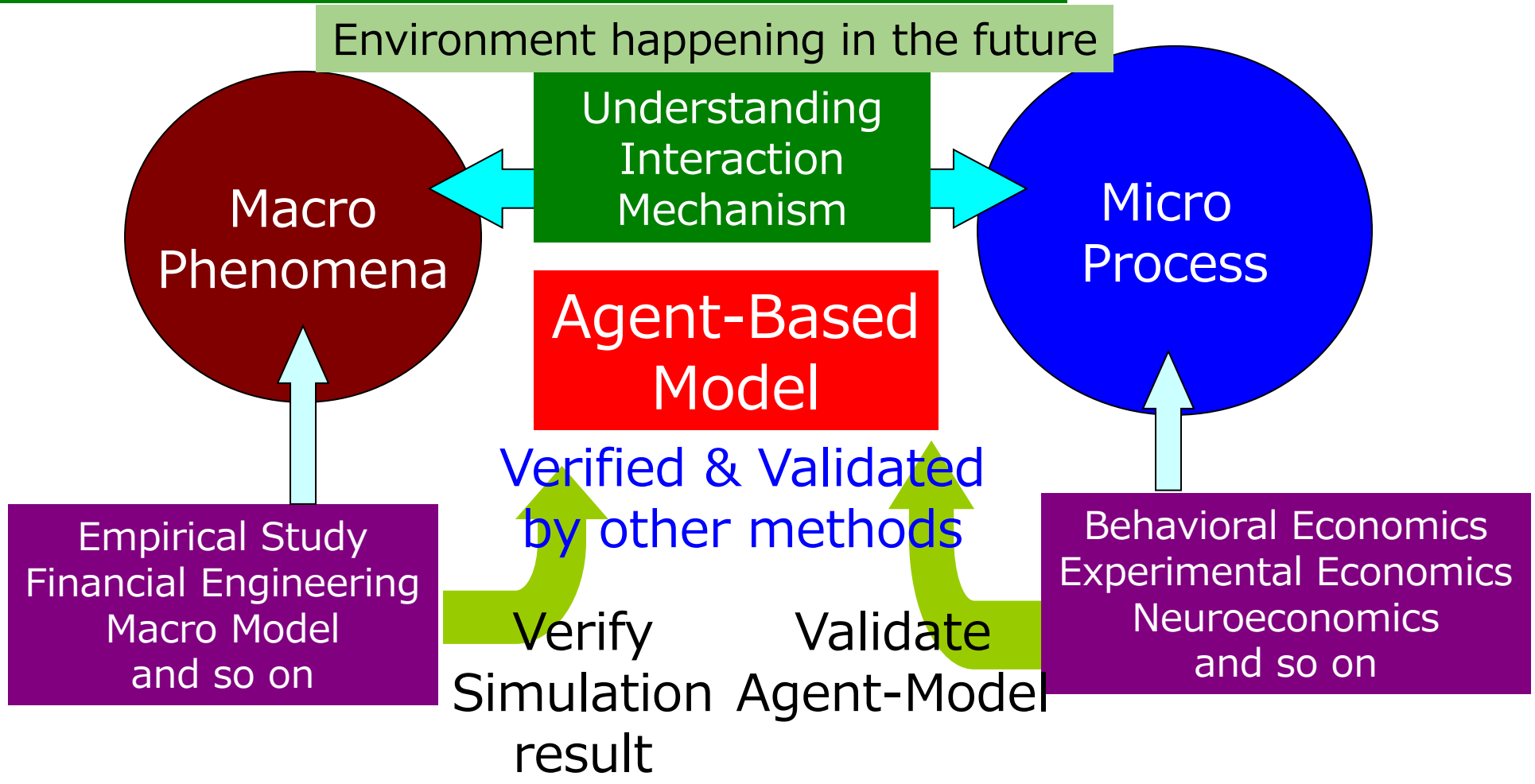
The advantage of an agent-based model is outputs include the part of the area happening in the future. The disadvantage, however, is outputs include the part of area not happening in the past or future.

An agent-based model just outputs “possible” results to understand the mechanism of a market. Discussing whether the results will occur or not needs other methods, e.g., an empirical study and a mathematical model.

Advantage: directly treat Positive Feedback (Self-Fulfilling Prophecy)



Collaborate to mutually compensate for their disadvantages



Discussing the outputs of an agent-based model always needs knowledge given by empirical studies and mathematical models. A market that works well should be designed by not one but several methods, and the methods should collaborate to mutually compensate for their disadvantages.

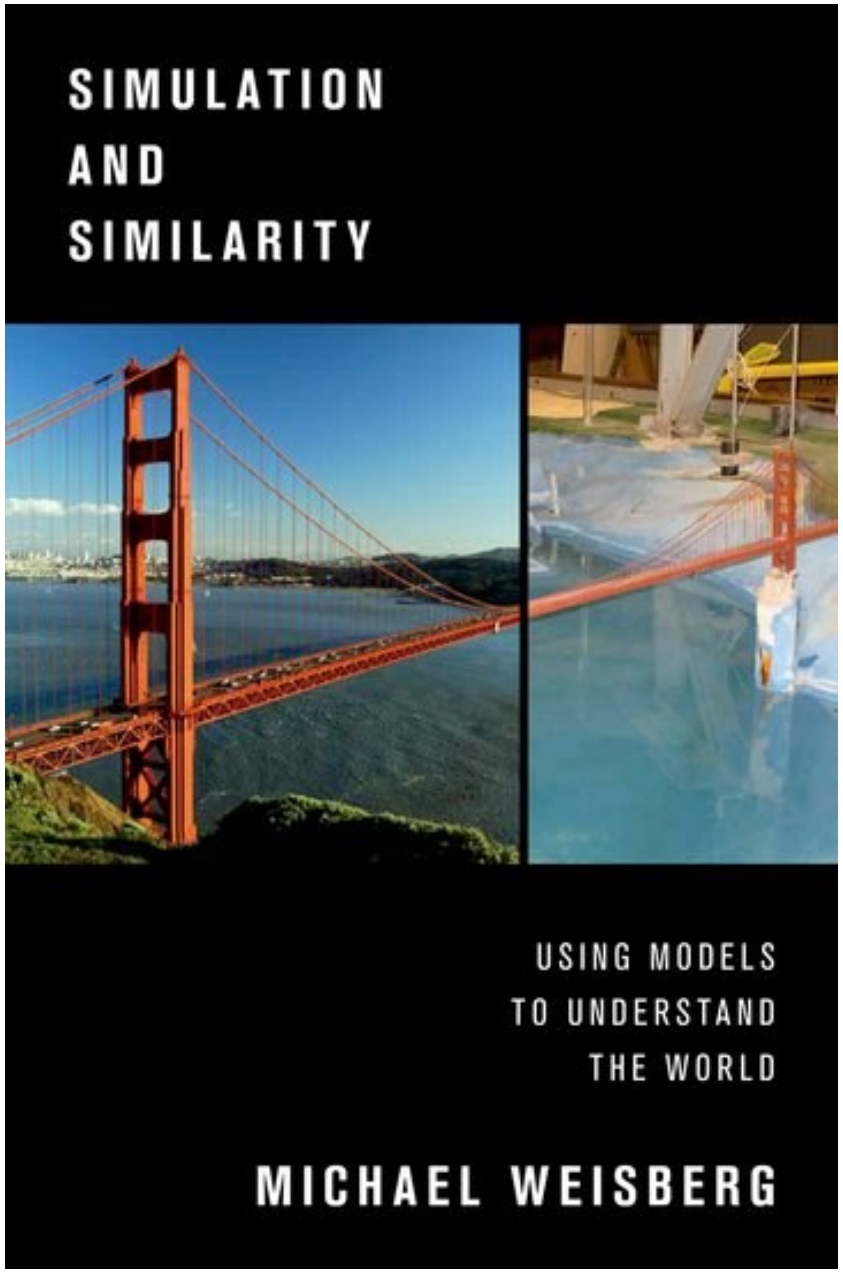
What is a role of Simulation Models? Suitable complexity?

Discussing the philosophy of models and simulations.

"What is a role of Simulation Models? "
"What is a model?",
"How complexity is suitable for the model?"

Very very good book.
I think all researcher who use some model should read this book for healthy discussion using models.

(Following some slides, I will introduce the discussion of the book)



Simulation and Similarity Using Models to Understand the World, 2012
https://global.oup.com/academic/product/9780199933662

Which ‘‘map’’ explains the access better?

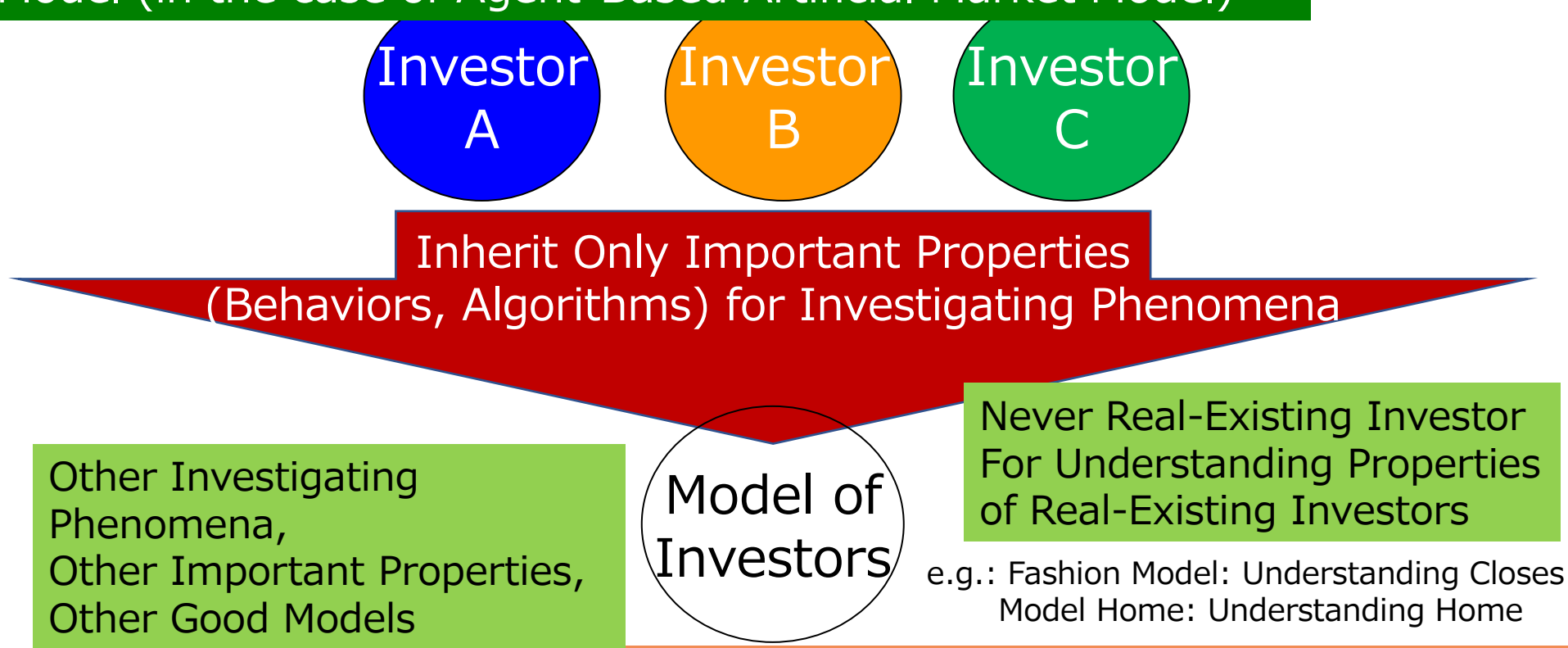
Some of maps are “models” of the real geography for understanding an access.

Very different from the real, however,
very good explaining the access.

Very similar to the real, however,
very bad explaining the access.

must shave non-investigating features from the model
Different investigations, different shaving parts.

Role of Model (in the case of Agent-Based Artificial Market Model)



An Aim is to understand how Important Properties (Behaviors, Algorithms) affect Investigating Macro Phenomena and play Roles in System.

It is NOT aim Replicating real-existing Investors A, B and C.
It is aim Understanding real-existing Investors.

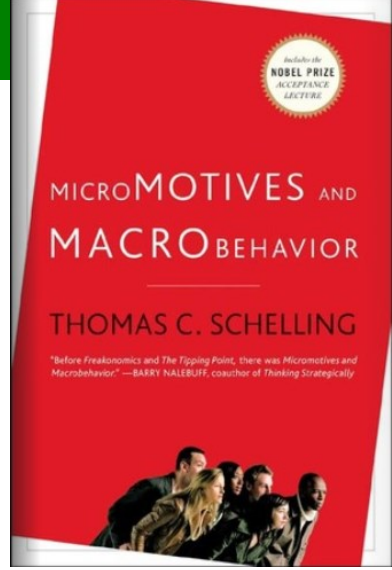
The simplicity of the model is very important because unnecessary replication of macro phenomena leads to models that are overfitted and too complex. Such models prevent understanding and discovery of mechanisms affecting price formation because of the increase in related factors.

Other Focusing Phenomena, Other Good Models; no model good for anything exist

Example of equation model cannot but simulation model can (Schelling Model)

Party with Students(#) and Professors(@)

Micromotives and Macrobehavior, 2006
http://books.wwnorton.com/books/978-0-393-32946-9/




```
    #     #  @  #     @
 #  #  #  @     @  #  @
    #  @           #  @  #
    @  #  @  #  @  #  @
 @  @  @  #  @  @  @
 #     #  #  #           @
    #  @  #  @  #  @
    @     @           #
```

Rules:
* around me (8pixs) with more 1/3 my equals -> not move
* No -> move
After many steps,,,

```
    #  #     @  #  #
 #  #  #  @  @  @  #  #
 #  #  @  @           @  #
 #  @     @     @  @  @
 @  @  @  #  @  @  @
    @  #  #  #  @  @  @
          #  #  #  #
 @  @                 #
```

and @ have been separated

Mod. rules:
#:need one more equal
@:need one less equal

```
 #  #  #  #  @        @
 #  #  #  #  @  @     @
 #  #  #  #        @
    @  #  @  @  @     @
 @  @  @  #  @  @  @
          #  #  @
       @  #  #  #  @
    @     @  #  #  #
```

The space of # is smaller

The segregation occurs even if we want not to be heavily minority. We do NOT hate other kinds.

The purpose of simulation is understanding the reasons and mechanism, not forecasting the final distribution.

Where are tables? How much they eat? Where are assistant professors?
Is the party place square? Are behaviors of people too simple?
---- Silly questions for the purpose of simulation.
prevent our understanding the mechanism.

Simplifying depends on that we want to understand

Schelling recommended you simulate this manually using coins to understand what is simulation model.

Role of Model (cont.)

We want know a relationship between
Micro Process:
Deciding Orders, Rules of Exchange
& Macro Phenomena: Price Formation

Mathematical Model
Macro Model

can treat only this region

Stock Market Country A

Bond Market Country A

Stock Market Country B

Replicate Only Important Properties

Price Formation (Simulation Result)

Model of Exchange

Model of Investors

Deciding Orders (Algorithms)

Inherit Only Important Properties

Investor A

Investor B

Investor C

Change Rules

Matching Orders (Aggregation of Algorithms)

We want know a relationship between them

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

(2) Suitable complexity, advantages and disadvantages

(3) Case study: tick size reduction

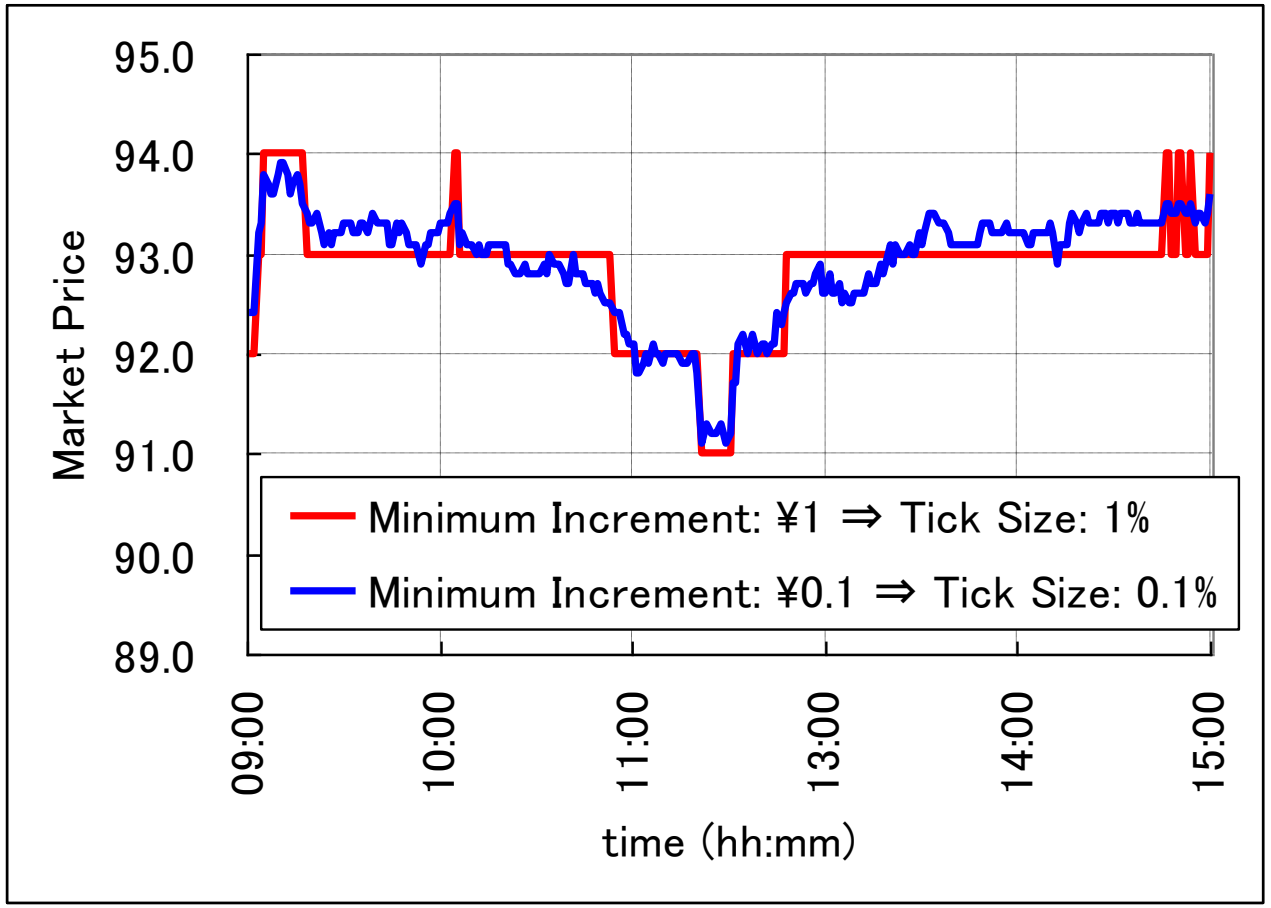
(4) Conclusion

Here, I very briefly introduce Mizuta et. al. 2013 as a typical study investigating the design of a financial market using an artificial market model.

Mizuta et. al. 2013, “Investigation of Relationship between Tick Size and Trading Volume of Markets using Artificial Market Simulations”, JPX working Paper Vol. 2

https://www.jpx.co.jp/english/corporate/research-study/working-paper/index.html

What is Tick Size?



Difference of 1% Return is Serious Problem for some Investors
⇒ They prefer Stock Market has Smaller Tick Size

Normal Agent(NA)

The model of Mizuta (2013) is based on Chiarella (2002).
The model is satisfied with stylized facts (statistical characteristics observed in actual financial markets).

Expected Return of each NA

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

Technical

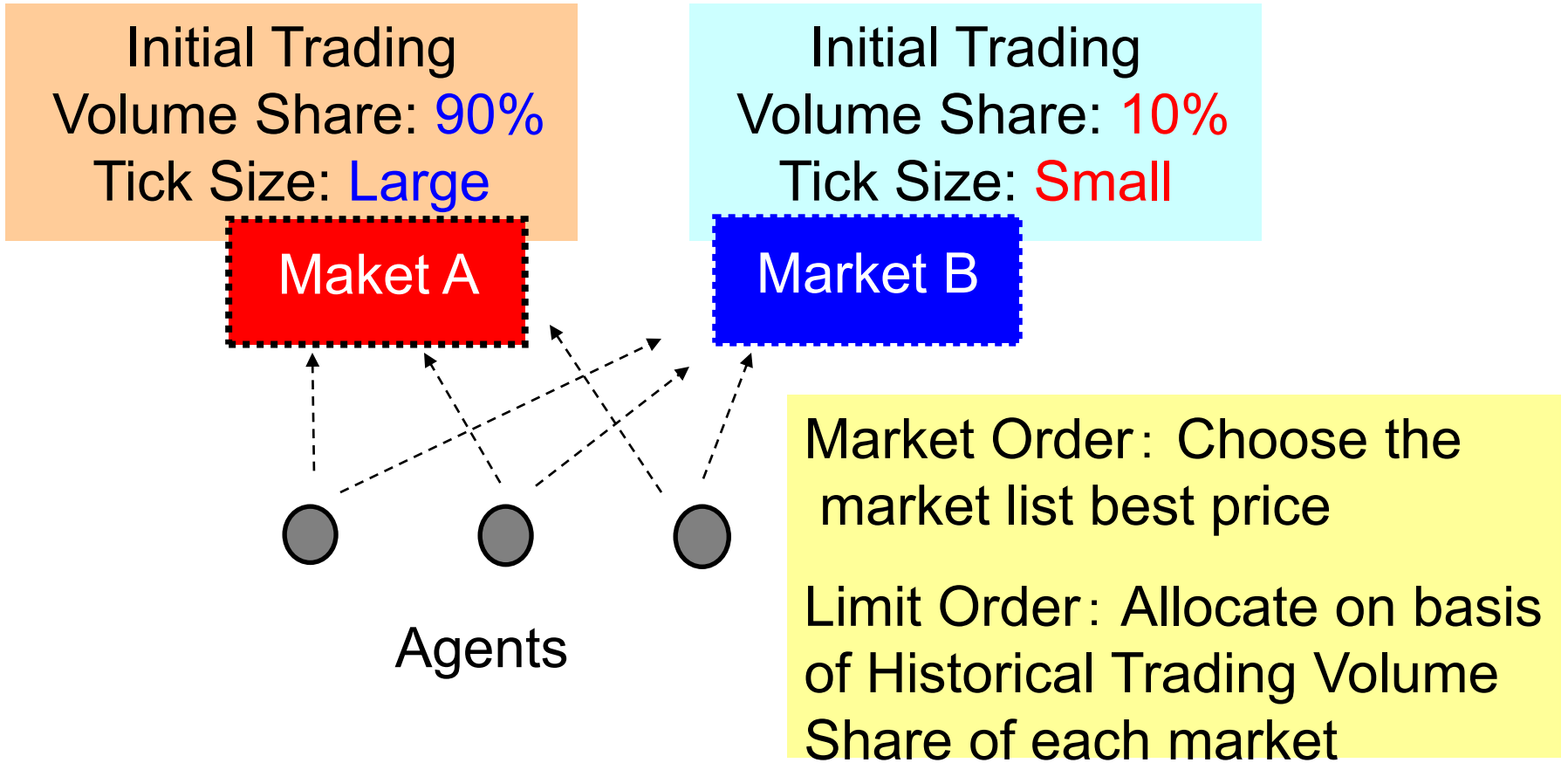
Fundamental

noise

All NAs use this same equation to obtain an expected return, however, because w is different each agents, expected returns are different each agents. This leads heterogeneous (many order prices are diversified) although the model is simple.

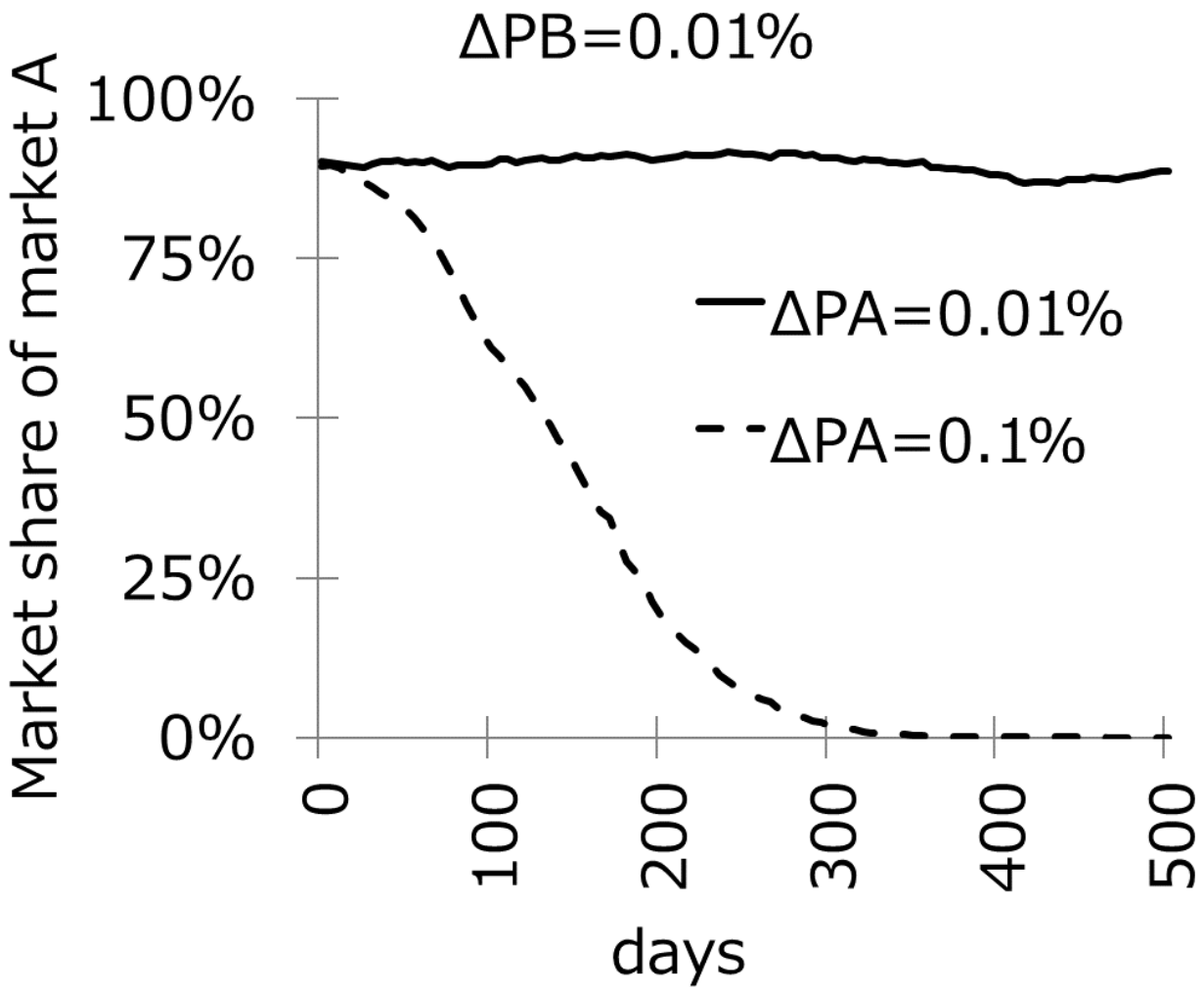
The simplicity of the model is very important.
Models include too many related factors prevent understanding and discovery of mechanisms affecting price formation.

Market Selection Model



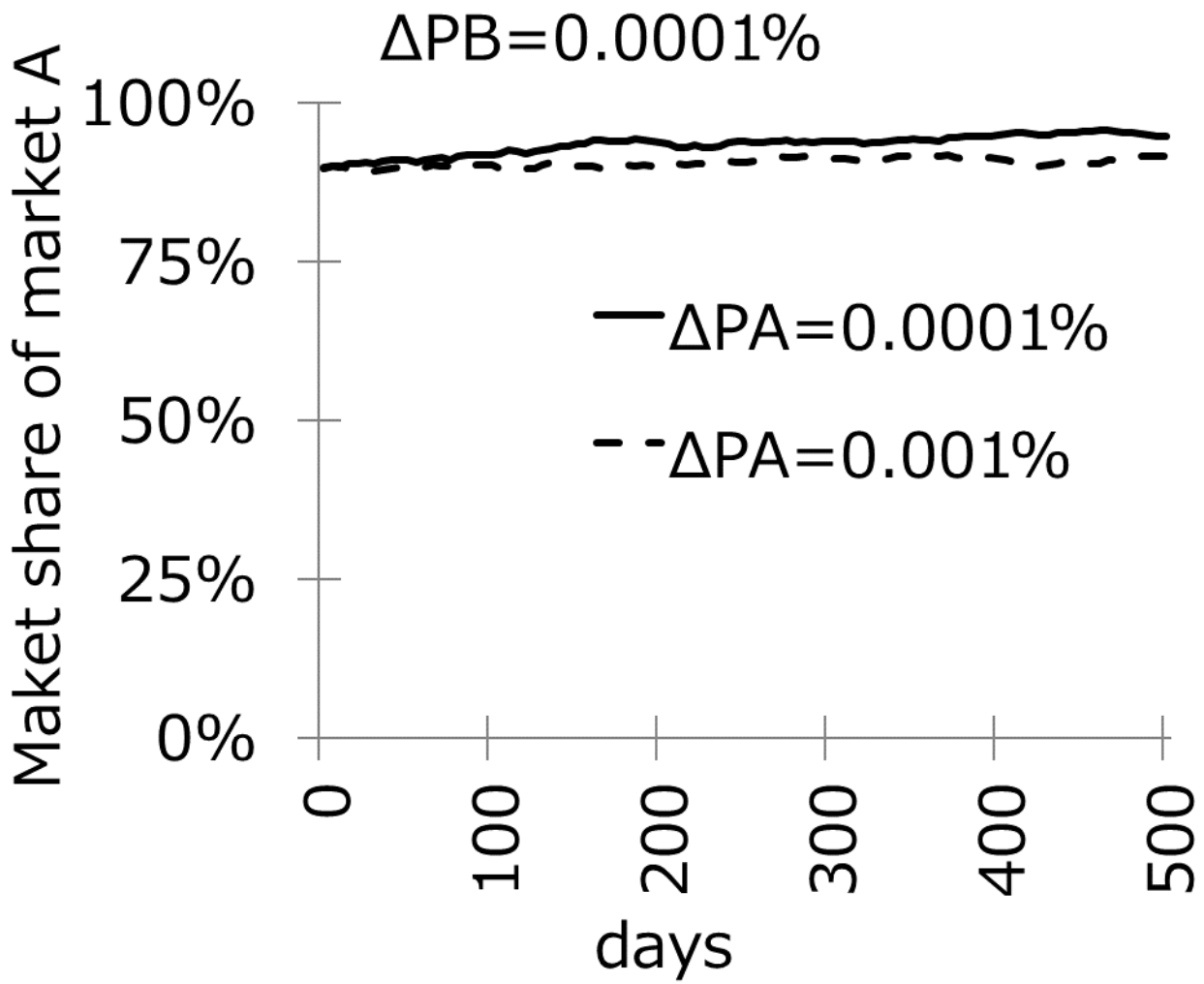
Market Order：buy or sell at the best available price, immediately
Limit Order：buy or sell at a specific price or better,
waiting opposite Market Orders

Tick Size of Market B is 0.01%, Tick Size is not small



Tick Size of Market A is large,
Market A is taken trading volume share

Tick Size of Market B is 0.0001%, Tick Size is enough small



Market B can hardly take the share in spite that Tick Size of Market A is very larger than that of Market B

Tick Size Condition Not to Move Share

Market share of market A at 500		Tick sizes of market B						
		0.001%	0.002%	0.005%	0.01%	0.02%	0.05%	0.1%
Tick sizes of market A	0.001%	90%	92%	94%	97%	99%	100%	100%
	0.002%	89%	91%	93%	97%	99%	100%	100%
	0.005%	84%	87%	92%	96%	99%	100%	100%
	0.01%	77%	78%	83%	92%	98%	100%	100%
	0.02%	54%	54%	59%	70%	93%	100%	100%
	0.05%	5%	5%	5%	6%	23%	93%	100%
	0.1%	0%	0%	0%	0%	0%	0%	94%

Condition Not to Move Share

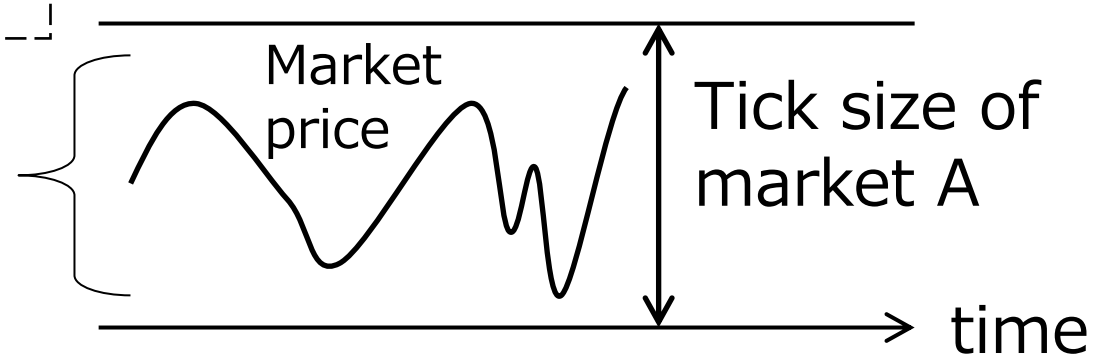
$\Delta P_B > \Delta P_A$ *or* $1/10\ \bar{\sigma}_t > \Delta P_A$

Condition to Rapidly Move Share

$\bar{\sigma}_t < \Delta P_A$

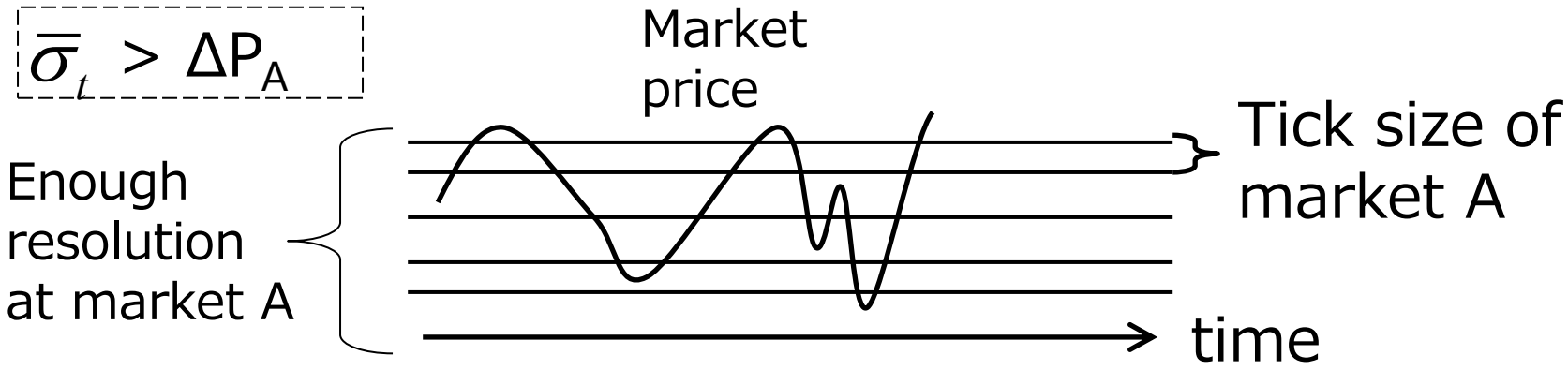
$$\bar{\sigma}_t = 0.05\%$$

$\bar{\sigma}_t < \Delta P_A$



Market A never represents movement of market prices. ⇒ Orders move to market B

$\bar{\sigma}_t > \Delta P_A$



Market A represents them. ⇒ not need market B

An Aim is to understand how Important Properties (Tick-Size) affect Investigating Macro Phenomena (Market Share) and play Roles in System.

It is NOT aim Replicating real-existing Investors and Market Prices, but understanding mechanism of the system.

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

(2) Suitable complexity, advantages and disadvantages

(3) Case study: tick size reduction

(4) Conclusion

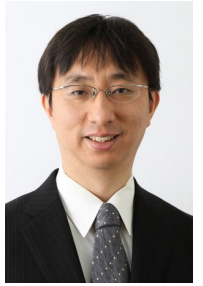
This study showed a philosophy of an agent-based artificial market model.
Why models are needed? How models should be? In the first place, what is a model?
We should understand what is a model deeper to discus healthy using a model.
I will try to clear up a common misunderstanding for a model.

Someone may think tick size reduction is a trivial matter for a financial market. This is, however, important and should not be underestimated. Changing detailed rules sometimes causes unexpected large impacts and side effects. John McMillan illustrated this nature as “both God and the devil are in the details''. Detailed design can determine whether a financial market develops or destroys an advanced economy. Designing a market well is very important for developing and maintaining an advanced economy, but not easy.

I hope that more agent-based artificial market models will contribute to designing a financial market that works well to further develop and maintain advanced economies.

An agent-based model for designing a financial market that works well

Takanobu Mizuta



Paper ID: #30

- ✓ Designing a financial market that works well is very important for developing and maintaining an advanced economy, but is not easy because changing detailed rules, even ones that seem trivial, sometimes causes unexpected large impacts and side effects.
- ✓ A computer simulation using an agent-based model can directly treat and clearly explain such complex systems where micro processes and macro phenomena interact. Recently, an artificial market model, which is an agent-based model for a financial market, has started to contribute to discussions on rules and regulations of actual financial markets.
- ✓ We should understand what is a model deeper for healthy discussion using a model. I tried to clear up a common misunderstanding for a model. Why models are needed? How models should be? In the first place, what is a model?
- ✓ The purpose of simulation is understanding the reasons and mechanism, not exactly forecasting the real world. 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. We must shave non-investigating features from the model. Different investigations, different shaving parts.
- ✓ I briefly introduced an artificial market model to design financial markets that work well and describe a previous study investigating tick size reduction. I hope that more artificial market models will contribute to designing financial markets that work well to further develop and maintain advanced economies.

Appendix

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
	lag	
autocorrelation coefficient for square return	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.

Detail of Expected Return

j: agent number (1,000 agents)
ordering in number order
t: tick time

Historical Return

$$r_{h,j}^{t} = \log(P^{t} / P^{t-\tau_j})$$

Technical

Expected Return of each NA

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

Parameters for agents

$w_{i,j}$ and τ_j

Random of
Uniform Distribution

$w_{i,j}$	i=1,3: 0～1 i=2: 0～10
τ_j	0～10000

Fundamental

P_f	Fundamental Price 10000 = constant
P^t	Market Price at t

noise

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

Expected Price of each NA

$$P_{e,j}^{t} = P^{t} \exp(r_{e,j}^{t})$$

Fundamental and Technical Strategies

Fundamental Strategy

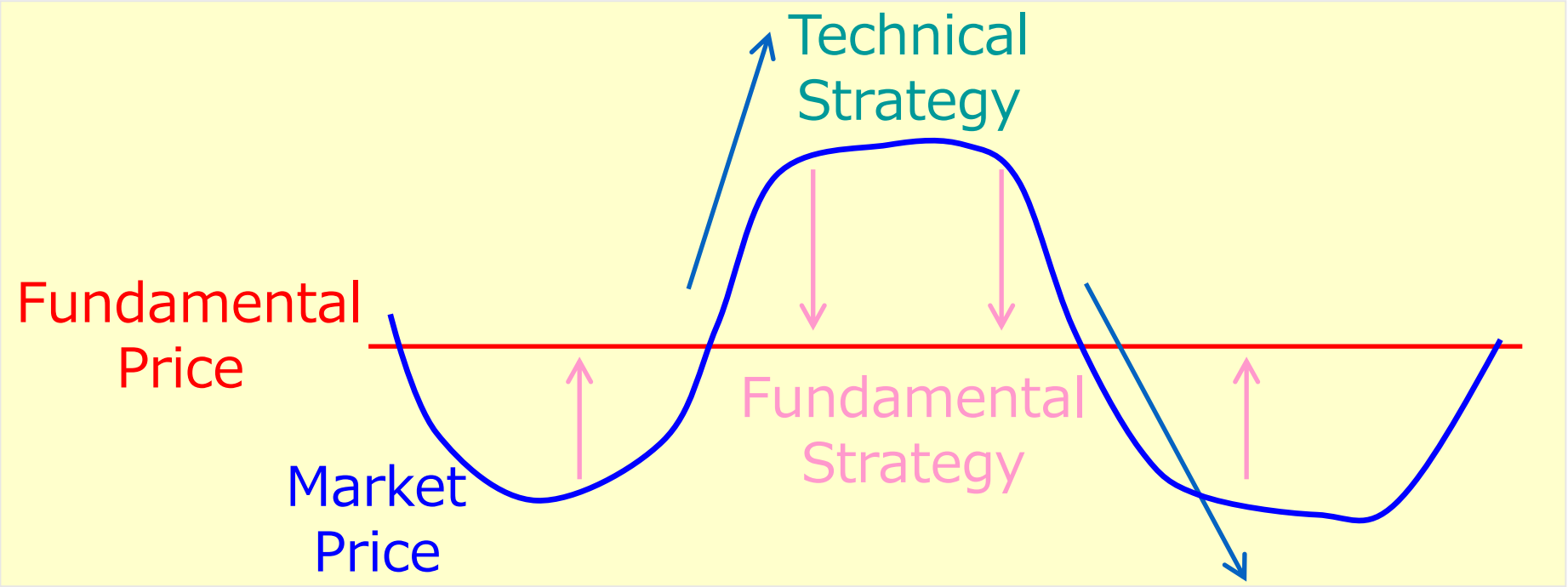
Fundamental Price > Market Price -> Expect + return

Fundamental Price < Market Price -> Expect - return

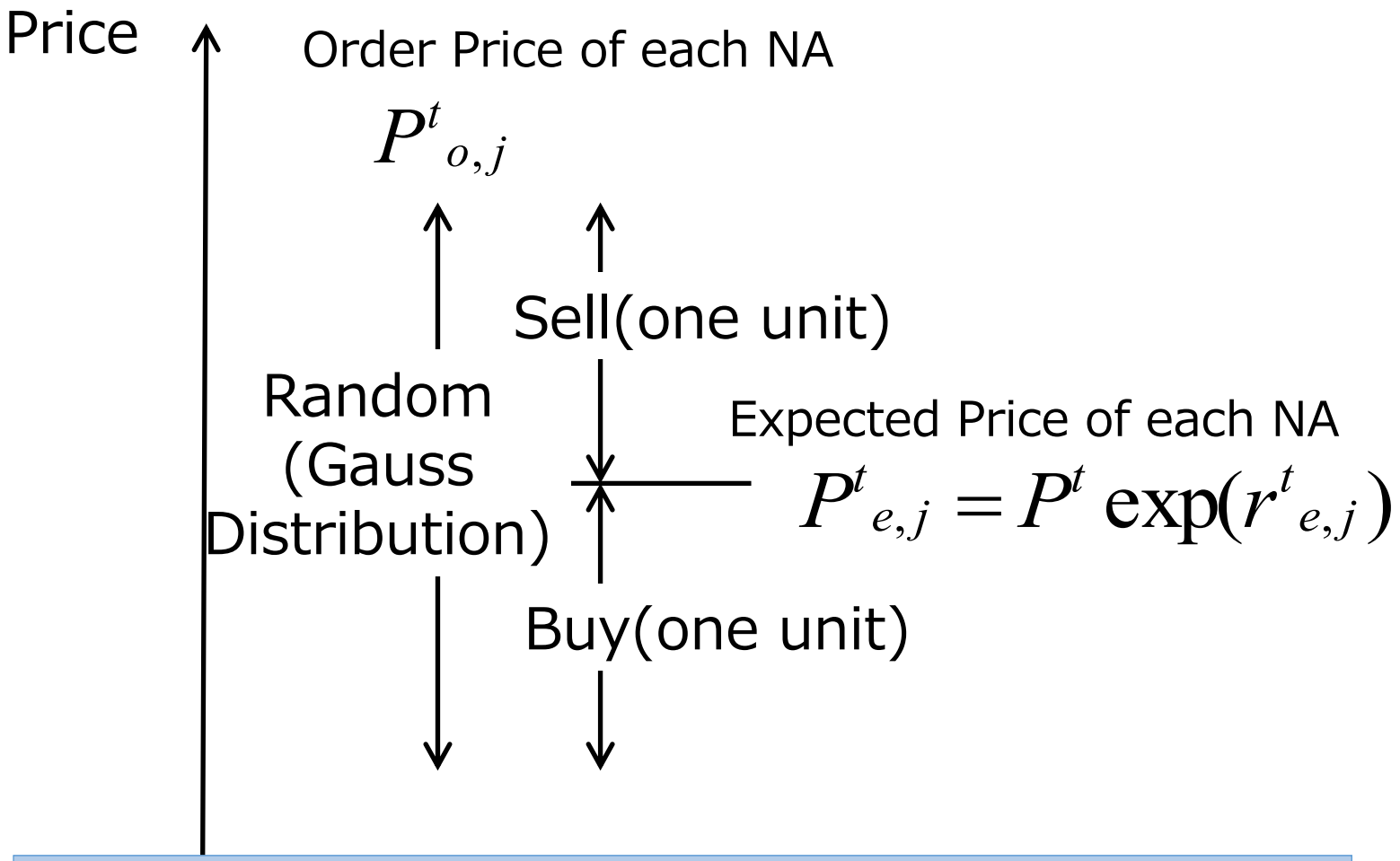
Technical Strategy

Historical Return > 0 -> Expect + return

Historical Return < 0 -> Expect - return



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