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HOW CARBON TAX CHANGE THE PERCEPTION AND BEHAVIOR OF PLAYERS IN A COMPETITIVE ENERGY MARKET?

Kengo SUZUKI

Department of Engineering Mechanics and Energy,

Faculty of Engineering, Information and Systems, University of Tsukuba

Ryohei ISHIWATA

College of Engineering Systems, University of Tsukuba

Background

The energy transition from fossil fuels to renewables has not reached a sufficient level in terms of mitigating catastrophic climate change.

To achieve the ambitious goals set out at the Climate Summit in this April, policymakers need to further introduce or improve energy and environmental policies.

The **carbon tax** is one of the most fundamental policies facilitating the energy transition. The rate of carbon tax in Japan is **less than 3 USD/t-CO2** : too low to encourage decarbonization by economic entities.

Therefore, the Ministry of the Environment in Japan is **discussing a plan to gradually raise the carbon tax rate**.

Expected Effect of Carbon Tax

The raise of carbon tax rate is expected to promote renewables by two mechanisms:

(1) Direct effect by raising the procurement cost of fossil fuels

(2) Indirect effect by the notice of future tax rates

The policymakers expect that the economic entities will progress decarbonation in advance when they are noticed the raise of carbon tax rate in the future.

These mechanisms includes the dynamics of multiple agents who have

[1] Rational thinking

[2] Subjective assessment of future uncertainties

How to estimate the dynamics of such multi-agent systems?

Game-Based Experiments

There are roughly three types of method to investigate characteristics of such a multi-agent system:

(1) Game Theory

(2) Agent Base Simulation

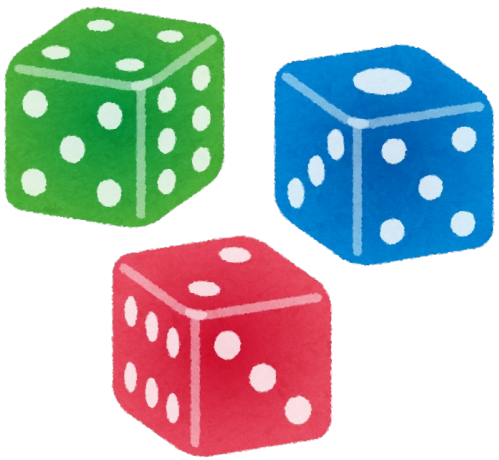
(3) Game-Based Experiment

Game-Based Experiment is suitable to investigate the relationship between the **subjective reality of economic entities and dynamics of target system as a whole**.

In the context of energy and environmental policies, this method has used to verify **whether the carbon market behaves as policymakers intended** by comparing the results of games under different treatments.

e.g. Shobe et al. (2014) https://doi.org/10.1016/j.jebo.2014.04.007

Dormady & Healy (2019) https://doi.org/10.1016/j.jcomm.2018.07.003



Purpose

Experimentally investigates the direct and indirect effects of carbon tax on energy transition in a competitive market by applying game-based experiments.

The experiments consisted of **gameplay** and **questionnaire surveys.**

(1) Records of gameplays represent **objective** aspects of the market

(2) Answers to questionnaire surveys represent **subjective** aspects of the market.

By comparing the results of games under **two conditions**,

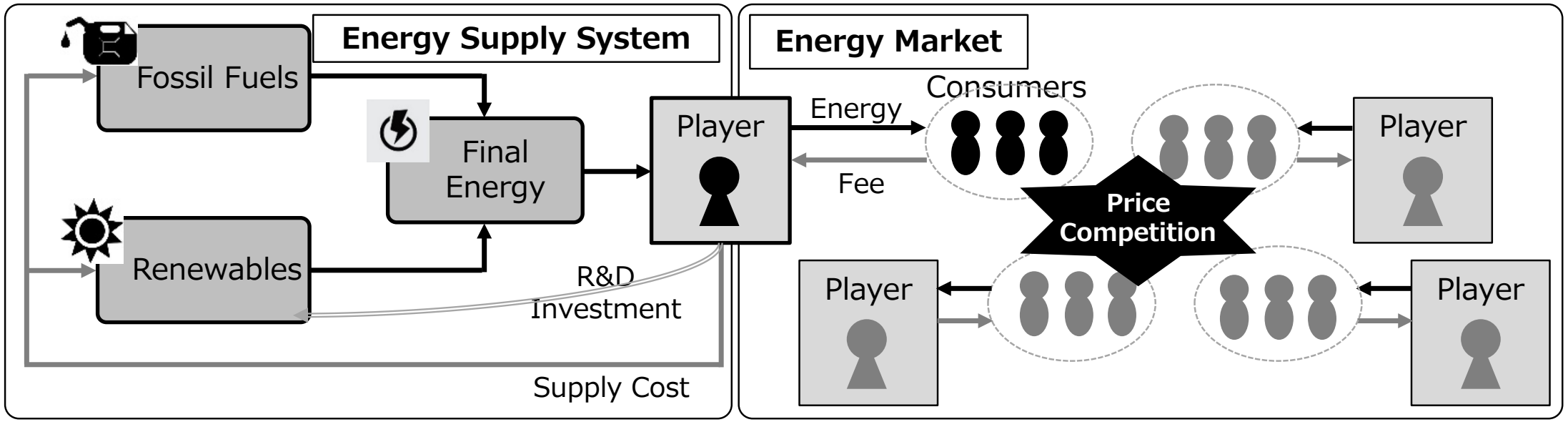
[1] Without carbon tax

[2] With carbon tax

we infer **the mechanism by which the carbon tax influences the selection of energy sources by market players.**

Multi-Player Game “Energy Transition”

- Each company make a profit by selling final energy produced from fossil fuels or renewables.
- In every round, the participants decides the energy mix, selling price, and the amount of R&D investment in renewables. The game continues 30 rounds while data up to the 25th round is used to avoid end effect.
- At the beginning, the cost for renewables is higher than that of fossil fuels while it decreases depending on the amount of investments. On the other hand, the price of fossil fuels rise over time.
- Consumers move from companies with higher selling price to these with lower selling price in every round.



Core Mechanics of "Energy Transition"

(1) Profit

$$\underbrace{V(i,t) - V(i,t-1)}_{\text{Profit}} = \underbrace{D(i,t-1)\, p_s(i,t)}_{\text{Revenue}} - \underbrace{E_r(i,t)\, p_r(i,t-1)}_{\text{Production Cost (Renewables)}} - \underbrace{\{D(i,t-1) - E_r(i,t)\} p_f(t-1)}_{\text{Production Cost (Fossil Fuels)}} - \underbrace{I(i,t)}_{\text{R\&D investment}}$$

(2) Change in Demand

$$D(i,t) - D(i,t-1) = \alpha \{ \underbrace{\mu(t) - p_s(i,t)}_{\text{Deviation of Selling Price from Average Value for all Players}} \}$$

(3) Production Cost for Renewables

$$p_r(i,t) = p_{r0} \underbrace{\{N(i,t)/N_0\}^{-\beta}}_{\text{Learning by Researching}} \underbrace{\{R(i,t)/R_0\}^{-\gamma}}_{\text{Learning by Doing}}$$

Parameter Settings

Parameters were set so that the game can represent the dilemma in competitive market: **conflict between long-term investment and short-term competition**.

Number of players (=5), **Number of rounds** (=30), and **Competition-related parameters**

-> Empirically set considering the results of preliminary experiments.

Other parameters

-> Set so that **the optimal solution for players satisfies these conditions**

(1) All final energy is produced from renewables at the final round of game.

(2) Total profit through the game is positive.

(3) Supply cost for renewables cannot be lower than fossil fuel in the first-half of game.

Experiment Environment

We constructed a completely remote experiment environment that does not require any physical contact between the experimenters and the participants.

(1) Implementation of the multiplayer game into a web application

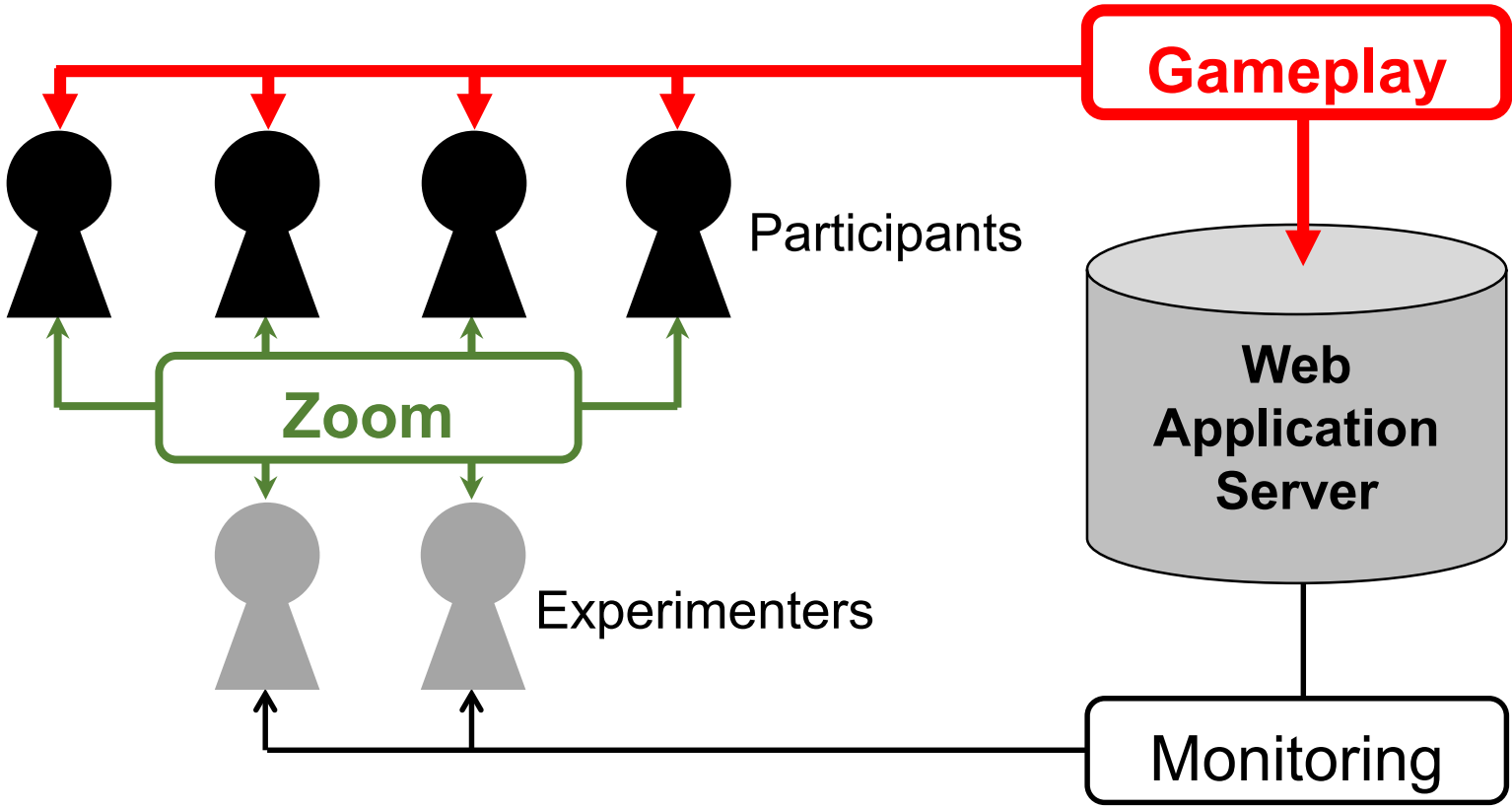
(2) Development of an operation method utilizing a video conferencing system (=Zoom).

Procedure

[1] Explanation (Zoom)

[2] Gameplay/Monitoring (Browser)

[3] Payment etc. (Mail etc.)



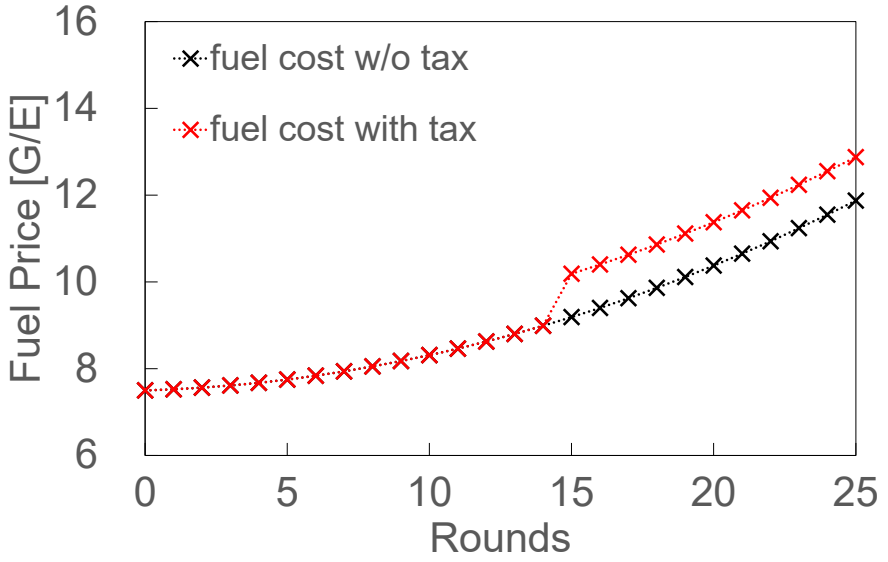
Summery of Experiments

Two Conditions (without and with carbon tax rules)

With-tax condition; carbon tax was introduced from the 16th round.

This taxation is equivalent to a rise in fossil fuel prices

Timing and tax rate were informed to the participants in advance.



Summery of Experiments

Participants: 56 students of University of Tsukuba

Number of game: 14 games; 7 games for with-tax and without-tax condition

Reward 2,000–4,000 JPY (approximately 20–40 USD)

Questionnaire Survey

In-game survey: Observing the changes in anxiety about uncertainty and the acceptability of tax

These questions were asked in every 5 rounds including just before the game start.

Post-game survey: Investigating the comprehensive understanding of gameplay by participants

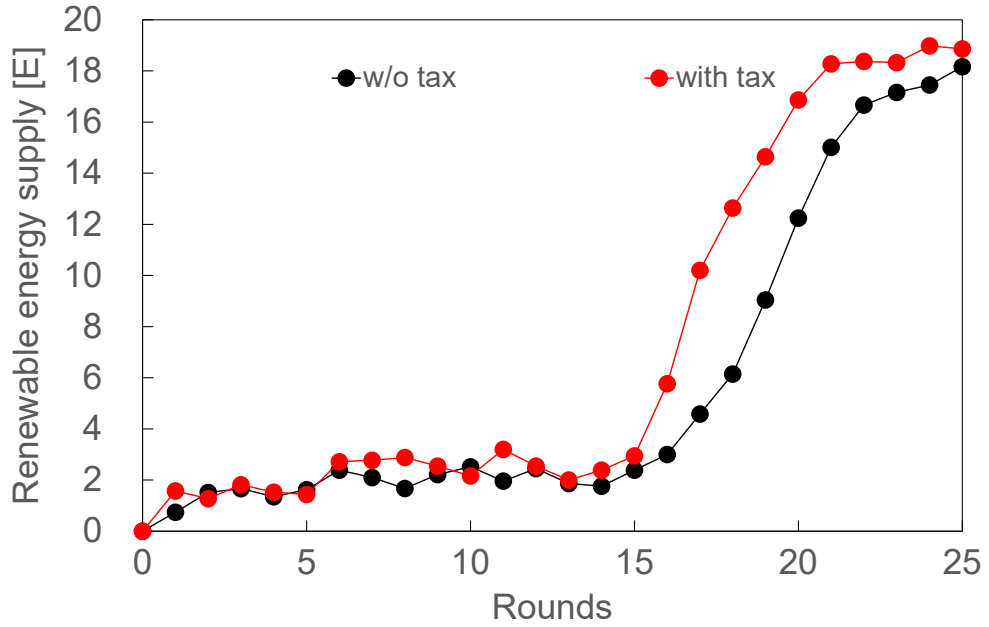
Summery of Experimental Results

	Summary Values		Mann-Whitney U test	
	Without Tax	With Tax	U-value	p-value
Renewable Energy Supply	**147.7**	**186.7**	**11**	***0.097**
Selling Price	9.7	9.9	18	0.443
R&D Investment	273.1	259.9	25	1.000
Profit	31.0	53.1	18	0.443
Renewables Supply Cost	9.9	9.8	25	1.000

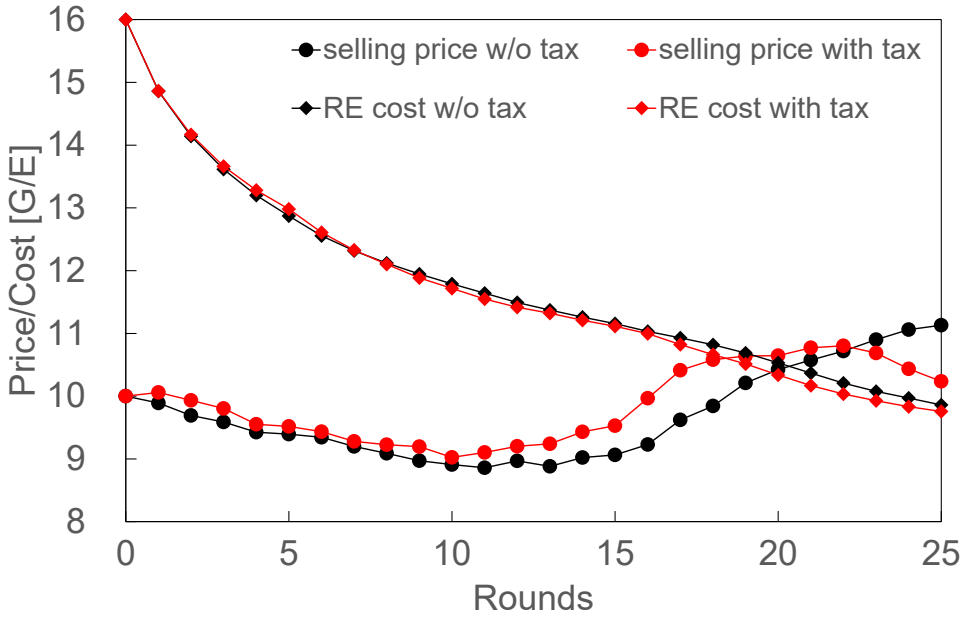
- **Total renewable energy supply through the game is larger in the with-tax condition (significant)**
- The final profit was higher in the with-tax condition (not significant)
- No noticeable difference in the other three summary values

Time Series Changes: Behavior

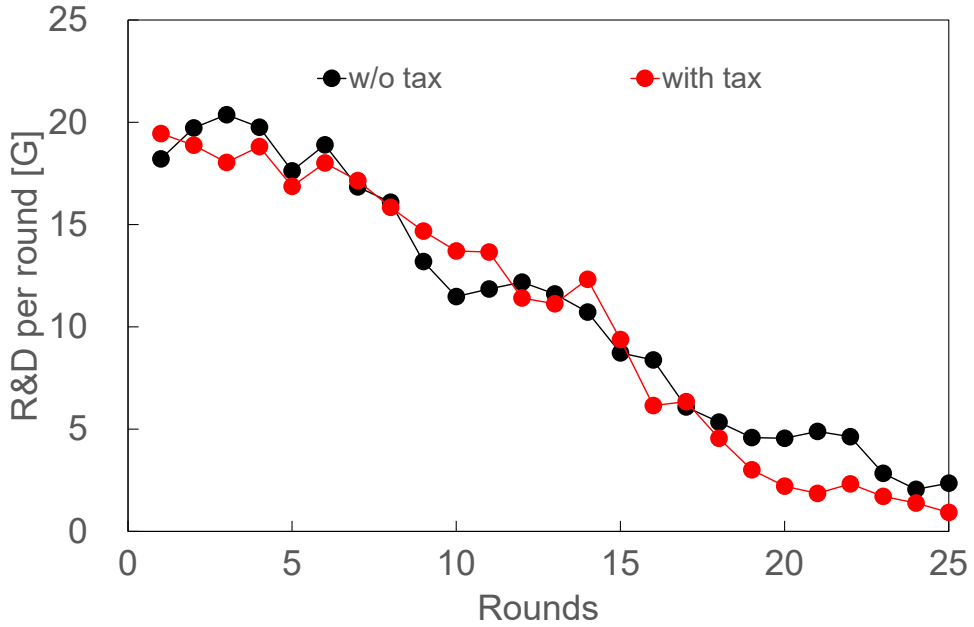
Renewable Energy Supply



Selling Price
RE Supply Cost



R&D Investment



- Rare of transition is higher in with-tax condition in the latter half of game
- Selling price is higher in the with-tax condition in the latter half of game

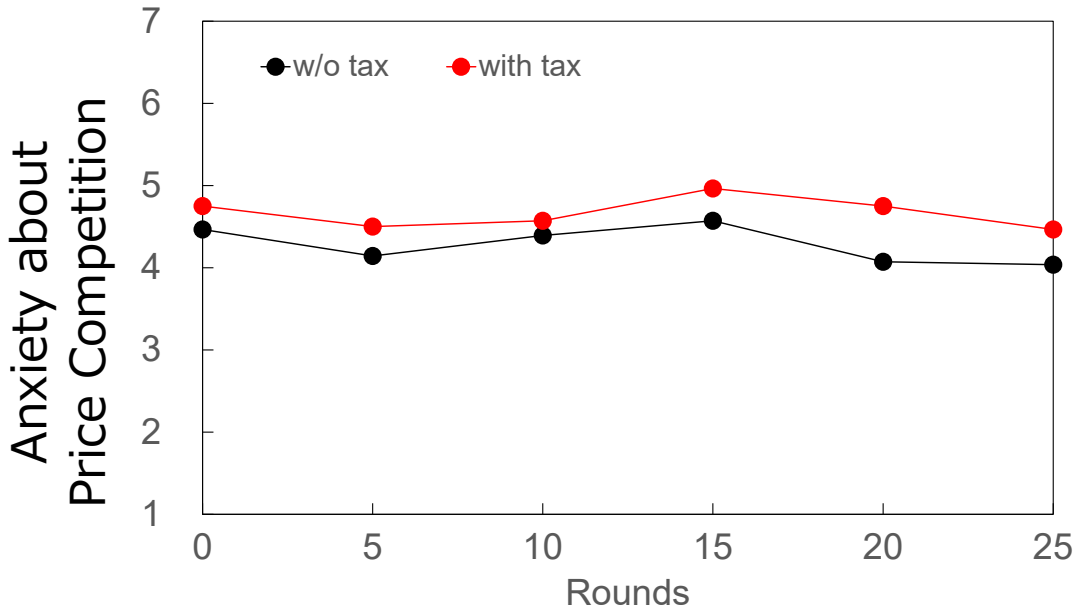
Time-Series Difference in Behavior

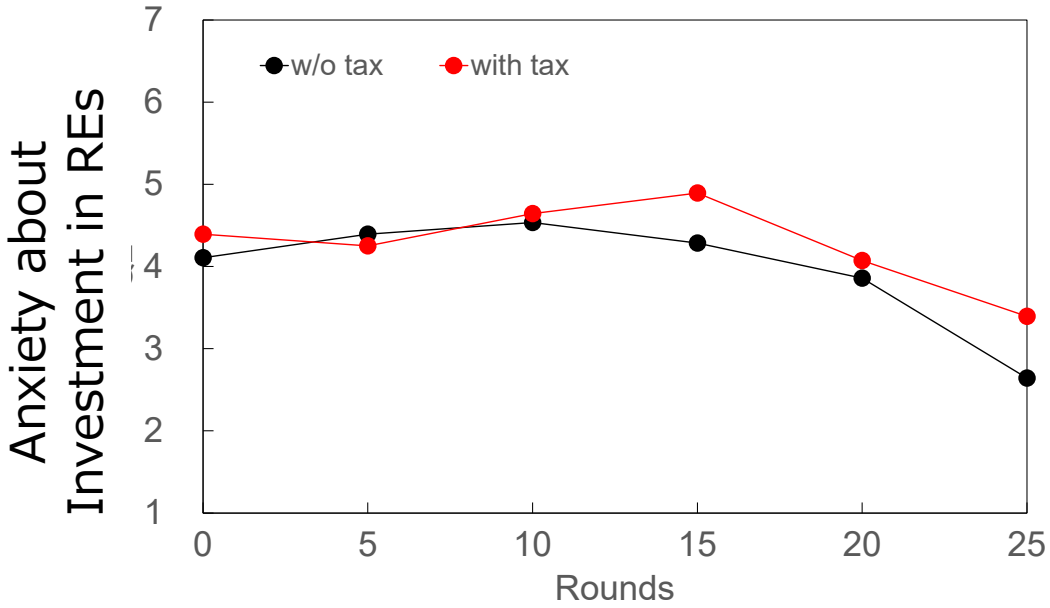
		Periods				
		1–5	6–10	11–15	16–20	21–25
Renewable Energy Supply	U-value	22.5	27.0	20.0	6.0	10.5
	p-value	0.848	0.798	0.609	**0.021	*0.084
Selling Price	U-value	21.0	25.0	22.0	11.0	34.0
	p-value	0.701	1.000	0.798	*0.097	0.250
R&D Investment	U-value	26.0	20.0	23.0	32.0	35.0
	p-value	0.898	0.609	0.898	0.371	0.201

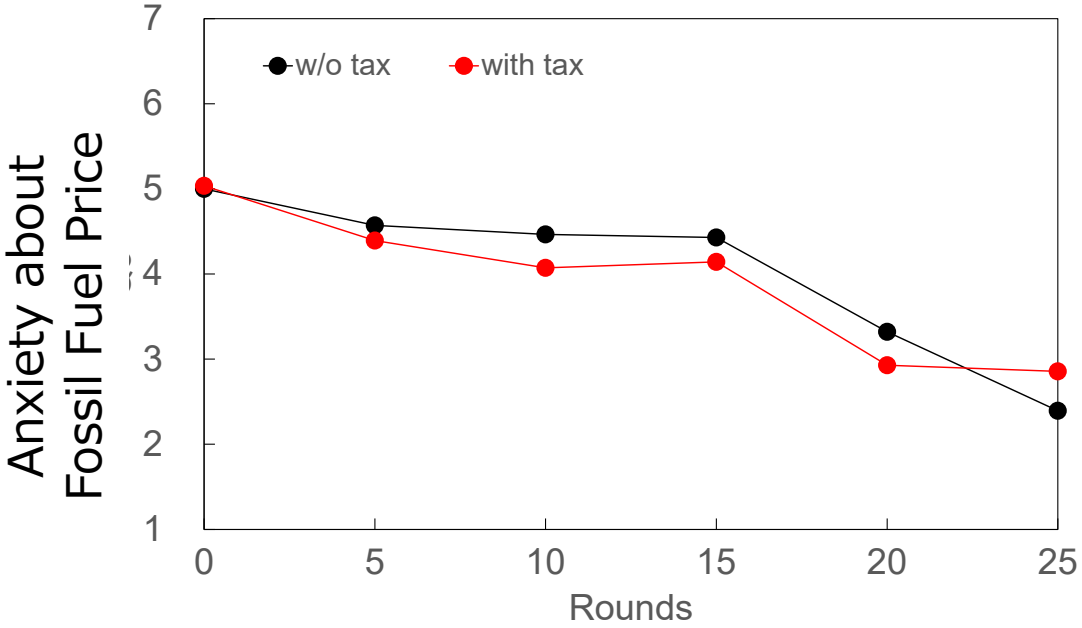
Significant Difference

- Renewable Energy Supply: 16–25 rounds
- Selling Price: 16–20 rounds
- R&D Investment: None

Time-Series Changes: Perceptions

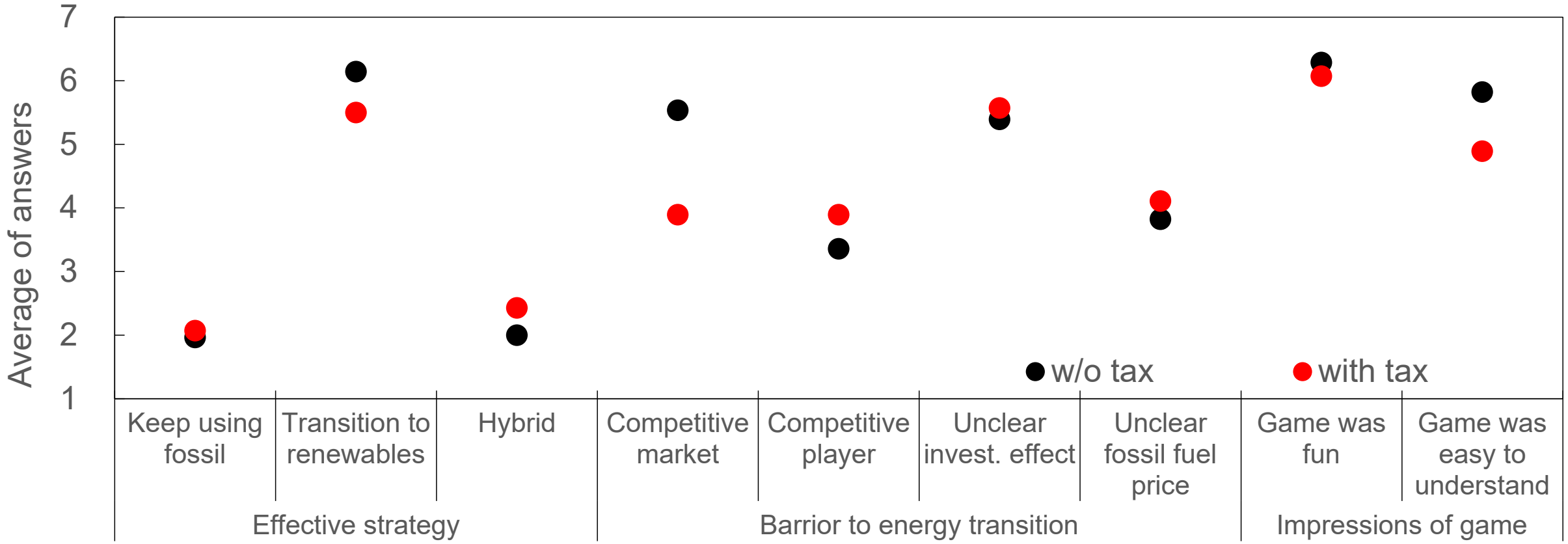






- No significant differences between conditions

Perceptions after Games



Players recognized that the strategy to complete the transition is the most effective.

Players regarded that the energy transitions was hindered by the unclear relationship between R&D investment and the unit price of renewables.

Competitiveness of market was also considered as the obstacle to transition under the without tax condition.

Discussions

Latter half: carbon tax accelerated the energy transition in the latter half of the gameplay

First half: carbon tax neither promoted the transition of energy sources nor the investment in R&D

These results suggest …

Carbon tax directly change the behavior of market players while the notice of taxation in advance does not change their behavior.

Anxiety of players during game was not prevented by the notice of carbon tax before the game start.

The results suggest …

The notice of future tax rate does not change the subjective recognition of uncertainty caused by investment in renewables.

Actually, the carbon tax reduces the absolute benefits of a strategy of using fossil fuels, but does not guarantee a relative advantage over a strategy actively promoting the energy transition. If fossil fuel prices rise only slowly, the fossil dependent strategy may keep relatively high profit even after taxation.

Conclusions

Among the expected effect of tax…

Direct effect by raising the procurement cost of fossil fuels **Observed**

Indirect effect by the notice of future tax rate **Not Observed**

These results suggest that carbon tax can contribute to energy transition **only when it is introduced as soon as possible**, and the **level of tax is high enough to convince energy companies that the active investment in renewable is the optimal strategy**.

Experimental study of energy market can be held even under the epidemic of COVID-19 by utilizing information technologies.

This remote environment is useful even after the end of epidemic: it makes the collection of participants and handling of experiments much easier and enables new types of research methods such as cloud experiments.

Acknowledgement

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Questionnaire Survey

In-game	**Anxiety about uncertainties**	Q1	How much are you anxious about you don't know if you can survive in price competition?
		Q2	How much are you anxious about you don't know if the investment in renewables make profit until the end of game?
		Q3	How much are you anxious about you don't know the future fuel prices?
	Acceptance of carbon tax	Q4	Do you think that the introduction of carbon tax will increase your profits?
Post-game	**Effective strategy**	Q5	I should have been adopted only fossil fuels.
		Q6	I should have completed transition to renewables.
		Q7	I should have used both fossil fuels and renewables until the end of game.
	Obstacles to transit energy sources	Q8	The whole market was competitive.
		Q9	Certain individuals were competitive.
		Q10	The relationship between R&D investment and the unit price of renewable energy was not quantitatively understood.
		Q11	The rate of increase in fossil fuel prices was not known quantitatively.
		Q12	Others (Free description)
	Impressions to game	Q13	Do you feel this game fun?
		Q14	Do you feel this game easy to understand?

Python-Django base software to support the development of web applications for experimental research in the fields of psychology and economics (Chen et al. 2016).

Since the developed game is deployed on the web application server, it can be played using any terminal with a web browser.

The oTree supports not only the development of application but also operation of experiments. Especially, the virtual experiment room is useful to handle multiple games simultaneously.