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

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Overview

The carbon tax is expected to have two effects in the context of encouraging energy transition from fossil fuels to renewables: direct changes in behaviours of energy companies due to the taxation itself and indirect changes in behaviours due to the notice of taxation in advance. The reaction of companies to the carbon tax can be inferred by experiments using games simulating real energy markets while large part of experimental studies on carbon pricing policies focus on the design of trading systems rather than the long-term impact of policies themselves. This study experimentally investigates the impact of carbon tax on the perception of risk and choice of energy technologies by the participants of a competitive energy market by using a multiplayer game. The experiments were conducted 7 times each under the conditions without and with the carbon tax. The objective and subjective data, i.e. record of gameplay and answer to questionnaires, were obtained from experiments. These experiments were completely remoted as a countermeasure against the COVID-19 pandemic. The results of gameplay indicate that the changes in behaviours of participants were limited to after taxation; there is no significant changes in their behaviours before taxation. The results of questionnaire survey indicate that there is no difference in the level of anxiety about price competition and uncertainties in return on investment in renewables perceived by the participants between two conditions. These results suggest that the notice of carbon tax cannot alleviate the level of risk perceived by market participants. In conclusion, the carbon tax must be introduced as soon as possible, and the level of tax must be high enough to convince participants that the active investment in renewable is the optimal strategy.

Keywords: Energy Transition, Carbon Pricing, Carbon Tax, Experimental Economics, Gaming Experiment

Introduction

The energy transition from fossil fuels to renewable energies has not reached a sufficient level in terms of mitigating catastrophic climate change despite the importance of transition is recognized by the policymakers and public all over the world. In 2019, the 84% of world primary energy demand is still covered by fossil fuels (BP 2020). In Japan as well, fossil fuels account for 85% of the primary energy supply in FY2019 (ANRE 2021) despite the political support to renewable energies such as the Feed-in Tariff. To achieve the ambitious goals set out at the Climate Summit in April 2021, policymakers need to further introduce or improve energy and environmental policies such as carbon pricing and feed-in premiums.

Nordhaus (2013) points out that one of the obstacles to mitigate climate change is the situation in which some countries prioritize their own benefits over the benefits of whole the world. This situation is a classic example of the social dilemma in which there is a discrepancy between the benefits of society as a whole and the benefits of its members (Dawes 1980). Theoretical and empirical studies of the social dilemma have revealed which types of social condition or policy affects the total benefit of multi-agent society. Findings from these studies suggest the importance of elucidating the conditions under which the optimal solution for whole the society is selected in a multi-agent system when designing policies to promote low-carbon energy sources.

The carbon tax is one of the most fundamental policies facilitating the energy transition from fossil fuels to renewables. The Ministry of the Environment in Japan is currently considering gradually raising the carbon tax rate because the rate of carbon tax in Japan is less than 3 USD/t-CO_2 in May 2021, which is too low to encourage decarbonization by economic entities. The increase in tax rates is expected to promote non-fossil fuel energies through two mechanisms: the direct effect by raising the procurement cost of fossil fuels and the indirect effect by the notation of future tax rates. These expectations needs to be validated by a model considering both the rational thinking and subjective assessment of future uncertainties by economic entities.

Large part of multi-agent system studies examining the effects of carbon taxes do not consider the subjective recognition of decision makers against uncertainties inherent in energy market because these studies employ a game-theoretic model which assumes all the information needed for decision-making is given in advance. On the other hand, there are some empirical studies clarified the mechanisms how the social rules such as sanctions and rewards change the recognition and behaviour of agents. These studies adopts experiments in which humans play games simulating the dilemma situation in the real world as a research method. For example, Kitakaji and Ohnuma (2019), whose theme is the illegal dumping of industrial waste, showed that the reward for waste disposal may increase the amount of illegal dumping because the reward discourages the participants not to solve problems through their own efforts. Like this, game-based experiments can discover and explain important possibilities that may be missed by other methods (Schelling 1964).

This study experimentally investigates the direct and indirect effects of carbon tax on energy source selection for the entire market using a multiplayer game that simulates an energy business in a competitive market. The experiment consisted of gameplay and questionnaire surveys, and was conducted for the two conditions: with and without carbon tax. Through an integrated analysis of the objective and subjective data obtained from the experiments, that is, the gameplay records and the responses to the questionnaire, we infer the mechanism by which the carbon tax influences the selection of energy sources by market players.

Model

Figure 1 is a conceptual figure of the multiplayer game "Energy Transition". Participants play the roles of energy companies in a competitive market. They make a profit by selling final energy produced from fossil fuels or renewables. The purpose of participants is to maximize their own profits. 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 (data up to the 25th period is used). At the beginning of game, 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.

The formal explanation of this game is as follows. There are M energy companies participating in the competitive energy market. The state of company i in round t is expressed by four variables: fund $V(i, t)$, final energy demand (= number of customers) $D(i, t)$, cumulative renewable energy production $R(i, t)$, and knowledge stock $N(i, t)$. The fund V increases due to sales revenue to customers and decreases due to payment of production costs and R&D investment.

$$V(i,t) - V(i,t-1) = D(i,t-1)\, p_s(i,t) - E_r(i,t)\, p_r(i,t-1) - \{D(i,t-1) - E_r(i,t)\}p_f(t-1) - I(i,t) \quad (1)$$

The first term is a revenue by selling final energy; p_s is the selling price of final energy. The second and third terms are the final energy production costs. E_r and $(D - E_r)$ are the final energy production from renewables and fossil fuel, respectively, and p_r and p_f are the unit production costs from renewables and fossil fuels. The fourth term I is the amount of R&D investment in renewable technology. The energy demand of the entire market, $\Sigma_i D$, is constant, while the demand for each company changes by the price competition; the demand moves from companies with relatively higher selling prices to the these with relatively lower selling price every period.

$$D(i,t) - D(i,t-1) = \alpha\{\mu(t) - p_s(i,t)\} \quad (2)$$

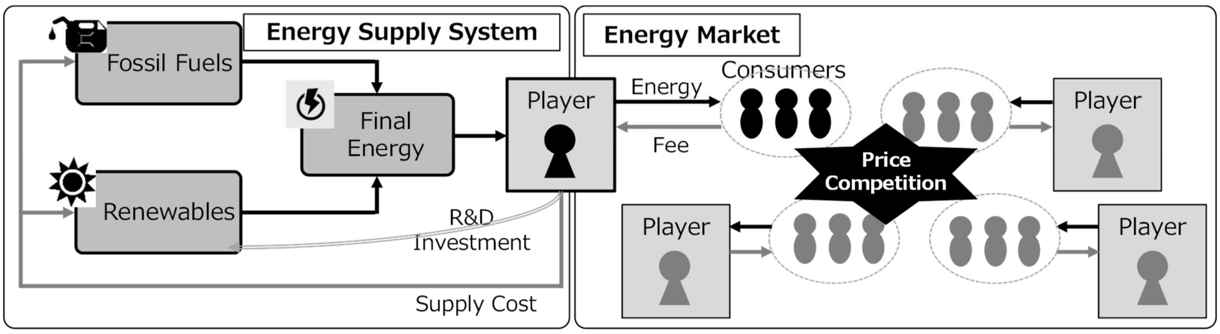
$\mu(t)$ is the market average of the energy selling price $p_s(i, t)$ in period t, and α is a parameter representing the sensitivity of demand to the selling price. The greater the difference between the selling price of each company and the market average, the greater the amount of changes in demand. However, since it is not realistic for the selling price to change too rapidly, the following restrictions are set with the maximum value of the change in the selling price for each round as m.

$$p_s(i,t-1) - m \leqq p_s(i,t) \leqq p_s(i,t-1) + m \quad (3)$$

The unit cost for final energy production from renewables decreases according to R&D investment and production.

$$p_r(i,t) = p_{r0}\{N(i,t)/N_0\}^{-\beta}\{R(i,t)/R_0\}^{-\gamma} \quad (4)$$

Figure 1: Conceptual figure of multiplayer game "Energy Transition".



The unit price of fossil fuel p_f (i, t) is given exogenously. The knowledge stock N (i, t) increases by the ε root ($0 \leq \varepsilon \leq 1$) of the R&D investment I (i, t). This expresses that long-term continuous investment is more effective than short-term concentrated investment if the total investment is the same.

$$N(i,t) - N(i,t-1) = I(i,t)^{\varepsilon} \quad (5)$$

The cumulative renewable energy production R (i, t) up to round t is simply expressed as follows.

$$R(i,t) - R(i,t-1) = E_r(i,t) \quad (6)$$

Equations (1), (5), and (6) are set based on the dynamic optimization model commonly used in the field of resource economics (Gupta 2015). Equation (4) is a general two-factor proficiency curve (Rubin et al. 2015). Equations (2) and (3) are equations originally devised by the authors. To help the understandings of players, a fictitious unit system is set as follows; a unit of energy, funds, knowledge, and prices are [E], [G], [K], and [G/E], respectively. The game is driven by the input of players: the energy mix E_r and $(D - E_r)$, selling price p_s, and the amount of R&D investment in renewables I.

The parameters of the model need to be set so that the model can represent the social dilemma in a competitive energy market. In the context of energy transition from fossil fuels to renewables, the social dilemma can be translated to the conflict between long-term investment and short-term competitions. To maximize the total fund of all companies at the end of the game, active investments in renewable technology is the best strategy. However, companies can increase their own profit by cutting off investment in renewables and reduce their selling prices. This situation in real world need to be represented by adjusting the parameters of the model.

The number of players, length of a game, and competition-related parameters were empirically set. The number of players, M, is set to 5 because both the competitive and non-competitive results are observed by this number. If the number of players is too small, cooperation becomes easy and price competition cannot be expressed. However, if the number of players is too large, the cost of conducting experiments becomes high. The number of rounds per game, T, is set to 30. An experiment consisting of the larger number of rounds provides the richer information while gives the higher load to participants. The competition-related parameters, m and α, were adjusted to 1 and 0.5 through test plays. While the price competition need to have a non-negligible effect on the final profit, the amount of change in demand per period must not be too large so that the lost in competition for few rounds does not determine the final profit.

Other parameters were set by using a mathematical programming model whose objective function is to maximize the total fund of all companies at the end of game ($\Sigma_i V(i,T)$). We adjusted the parameters so that the optimal solution of the model satisfies the following conditions. First, all final energy is produced from renewables at the final round of game. Second, the final value of fund must be larger compared with its initial value to guarantee that the investment in renewable technology makes profits. Third, the unit price of renewables and fossil fuels never reverse in the first half of the game. This condition is necessary to ensure that the energy transition is not too easy; players are required to continuously invest in renewables before recovering their investments. Finally, the parameters of the model were set as follows. Table 1 shows the set of parameters used in this study.

Table1: Parameter settings.

Symbol	m	α	β	γ	ε	V_0	D_0	p_{r0}	P_{s0}	R_0	N_0
Unit	[G/E]					[G]	[E]	[G/E]	[G/E]	[E]	[K]
Value	1	0.5	0.07	0.13	0.79	20	5	16	10	4	4

Experiments

The game-based experiments were planned to be held at laboratory; the participants and experimenters were supposed to gather in a same room. The game application was implemented to laptop computers, which were used for terminals for players and a game server for experimenters, and these computers were connected via Wi-Fi. However, the epidemic of COVID-19 has made such a laboratory experiments difficult. Therefore, we newly constructed a completely remote experiment environment that does not require any physical contact between the experimenters and the participants. For the purpose, we implemented the multiplayer game into a web application, and developed an operation method utilizing a video conferencing system.

The oTree was adopted for the development of web application. The oTree is based on Django, a Python-based web application development framework, and has useful functions to support the development and operation of 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.

In each round, the participants receive feedback on the actions of the previous round in the form of messages, graphs, and tables, and inputs their next decisions. These input are sent to the server via the internet, and the results are calculated and fed back again.

The experimental environment consisted of a web server on which the game application was deployed, a PC used by the experimenters and participants, and the internet. A web browser and Zoom need to be installed to the PCs for experimenter and participants. A unique URL issued to each participant was required to access the web server.The experimenters sent the Zoom address and unique URL to each participant in advance. At the beginning of the experiment, participants accessed the Zoom address from any location and received the explanation of experiment outline, contract procedure, and game operation from the experimenters. After that, the participants played the game using a web browser. The experimenter monitored the progress of the game via a web browser and received any questions from participants on Zoom. All communication with participants, experimenters, and servers was via the internet. After the experiment, the experimenters received a set of documents by mail, etc., and transfers the reward to the account designated by the participants.

The experiments were conducted under two conditions: with and without carbon tax rules. In the with-tax condition, the carbon tax of 1 G per unit of fossil fuel was introduced from the 16th round. This taxation is equivalent to a rise in fossil fuel prices, as it is assumed that tax revenues will not be returned to the market. The timing of the introduction and the tax rate were informed to the participants before the game started.

The 56 students of University of Tsukuba were participated in 14 games; 7 games for with-tax and without-tax condition. The average time required for the experiment was about two and a half hours, and a reward of 2–4 thousand JPY, approximately 20–40 USD, was paid according to the final fund of the game. In these experiments, the subjective reality of the participants were investigated by a questionnaire survey incorporated into the web application. There were two types of surveys: in-game and post-game survey. The purpose of in-game survey is to observe the dynamic changes in anxiety about uncertainty and the acceptability of the carbon tax during game. The participants were asked in 7 stage questions at the start of the game and at the end of 5th, 10th, 15th, 20th, and 25th rounds (Q1-4 in Table 2). The purpose of post-game survey is to investigate the comprehensive understanding of participants. Here, we investigated their perceptions about the effective business strategies, the factors hindering energy conversion, and impressions of the game (Q5-14 in Table 2).

Table2 Questionnaire survey during and after the gameplay.

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?

Results

Table 3 shows the summary values of results in gameplays under two conditions: without and with the carbon tax. These values were calculated as follows. First, we prepared the summary values of each gameplay. For renewable energy supply, R&D investments, and profits, the cumulative values until the 25th round were calculated. For the selling price of final energy, the average value through the 25 rounds was calculated. For the unit price of renewable energy supply, the value at the 25th period was used. Then, the summary values of each gameplay were averaged for each condition. The renewable energy supply was higher in the condition with tax than in that without tax. As a result of the Mann-Whitney test, a significant difference was found between these conditions at the 10% level. The profit was higher in the condition with tax while no significant difference was observed. There was no noticeable difference in the other three summary values.

Figures 2 (a)–(d) show the time-series changes in renewable energy supply, supply costs for energy sources, selling prices for final energy, R&D investments, and profits in the conditions without and with carbon tax (black and red lines). These values are the means of seven games in each condition. Figure 2 (a) shows that the transition from fossil to renewables occurred after the 16th period in both conditions and the rate of transition is higher in the condition with carbon tax. Figure 2 (b) shows that the selling price decreased until the 10th round and then started to rise in both conditions; the rate of increase is larger in the condition with tax. Figure 2 (c) shows that the R&D investment decreased as the games proceed in both conditions. There was no noticeable difference in the amount of investment between these conditions. Figure 2 (d) shows that the profit in each round decreased in the first half of the game and starts to increase in the second half. In the first half, it is difficult to make a profit due to price competition, rising fossil fuel prices, and investment in renewable energy. On the other hand, in the latter half, it is not difficult to make a profit because the cost for supplying renewable energy is reduced as shown in Figure 2 (b).

Table 4 shows the results of the Mann-Whitney U test between the two conditions for time series data: the total renewable energy supply, average selling price, and total R&D investment for every five rounds. There were significant differences in the renewable energy supply in the 16–20 and 21–25 rounds, and in the selling price in the 16–20 rounds. There was no significant difference in R&D investment during any rounds.

In summary, the carbon tax accelerated the energy transition from fossil fuels to renewables in the latter half of the gameplay. On the other hand, in the first half of gameplay, the carbon tax neither promoted the transition of energy sources nor the investment in research and developments. These results suggest that the taxation to fossil fuels can directly change the behaviour of market players while the notice of taxation in advance does not change the behaviour of them.

Table 3: Summary of experimental results in 25th round (* Indicates significance in 10% level).

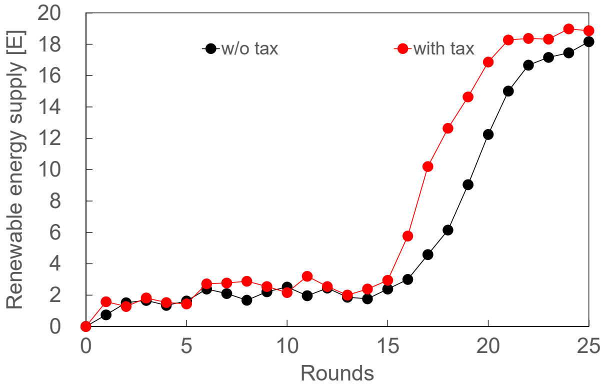
	Summary Values		Mann-Whitney *U* test	
	Without Tax	With Tax	*U*-value	*p*-value
Renewable Energy Supply	147.7	186.7	11	*0.097
Selling Price	9.7	9.9	18	0.443
R&D Investment	273.1	259.9	25	1.000
Profit	31.0	53.1	18	0.443
Renewables Supply Cost	9.9	9.8	25	1.000

Table 4: Results of the Mann-Whitney U test for time series data (*/** indicates significance in 10% / 5% level).

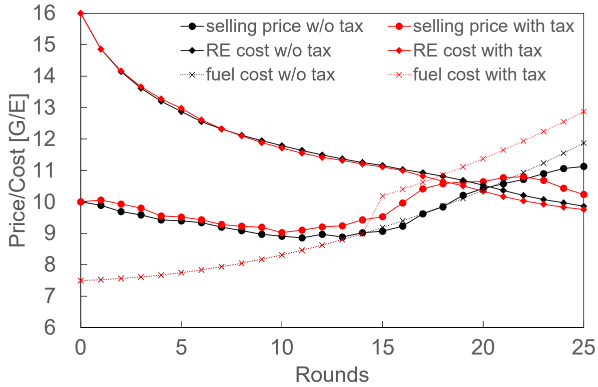
		Periods				
		1–5	6–10	11–15	16–20	21–25
Renewable energy supply	*U*-value	22.5	27	20	6	10.5
	p-value	0.848	0.798	0.609	**0.021	*0.084
Selling price	*U*-value	21	25	22	11	34
	p-value	0.701	1	0.798	*0.097	0.25
R&D investment	*U*-value	26	20	23	32	35
	p-value	0.898	0.609	0.898	0.371	0.201

Figure 2: Time-series changes in the status of gameplays under the conditions without and with carbon tax.

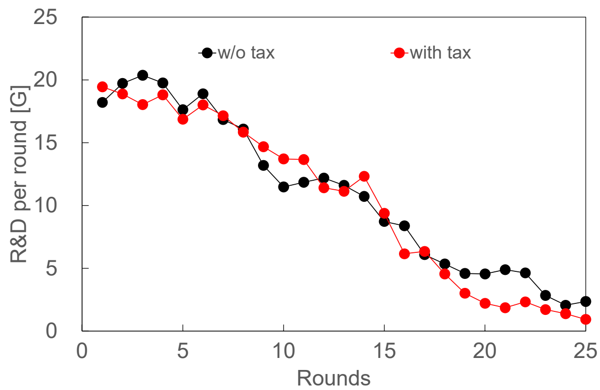
(a) Renewable energy supply



(b) Supply cost and selling price



(c) R&D investment



(d) Profit

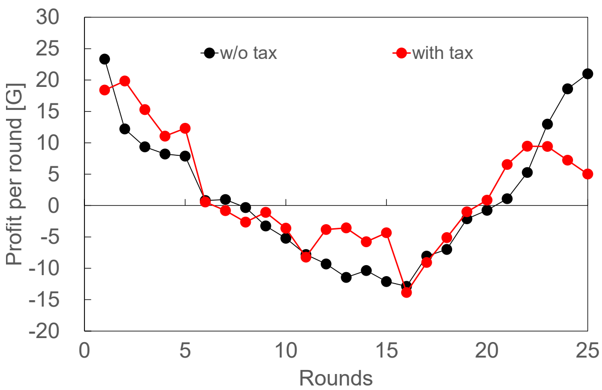


Figure 3 (a)–(d) show the time series changes in the answers to the in-game questions about the anxiety against uncertainties and the acceptance of carbon tax (Q1–4 in Table 2). The plot in the figures show the average value of all players participated in each condition (28 playrers each). The anxiety about price competition (Q1) was between 4 and 5 through the gameplay under both conditions. The values in the condition with tax were higher than these in the condition without tax in all rounds while there was no statistically significant difference according to the Mann-Whitney U test. The anxiety about renewable energy investment (Q2) and fossil fuel prices (Q3) were decreased in the latter half of the gameplay under both conditions. No statistically significant difference was found in the answers to these questions. The acceptability of carbon tax (Q4) is higher under the condition without tax; a significant difference was observed at the 1% level in the 15th period. These results suggest that the behavioral change due to the introduction of the carbon tax was due to a decrease in the profit from fossil fuel rather than a reduction in the anxiety about the uncertainties. The anxiety of players was not prevented by the notice of taxation before the game start; the level of anxieties were not reduced in the condition with tax.

Figure 4 shows the answers to the post-game questions (Q5–Q14 in Table 2, except for Q12). First, players recognized that the strategy to complete the transition is effective while other two strategies are not (Q5–7).There is no statistically significant difference between the conditions. Second, players regarded that the energy transitions was hindered by the unclear relationship between R&D investment and the unit price of renewables (Q10). Further, the competitiveness of market was also considered as the obstacle to transition under the without tax condition (Q8); the average value of answer is higher compared with the condition with carbon tax at the 1% level. Regarding the impression of the game, many participants felt that the game was fun and not difficult to understand under the both conditions (Q13 and Q14).

Discussions

The results of experiments suggest that the notice of carbon tax in advance does not change the perception and behavior of energy companies while the actual taxation can directly change their behavior toward the energy transition. The notice of taxation before the start of games failed to eliminate the anxiety of players hindering the investment in renewable energy. From the perspective of market players, the carbon tax reduces the absolute benefits of the strategy continuously utilizing fossil fuels, but does not guarantee the relative superiority of the strategy to actively promote the renewable energy. As far as the price of fossil fuel slowly rise, the reliance on fossil fuels may be more profitable compared with the transition to renewables even with the taxation to carbon emissions.

Figure 3: Time-series changes in answers to in-game questionnaire under conditions without and with carbon tax.

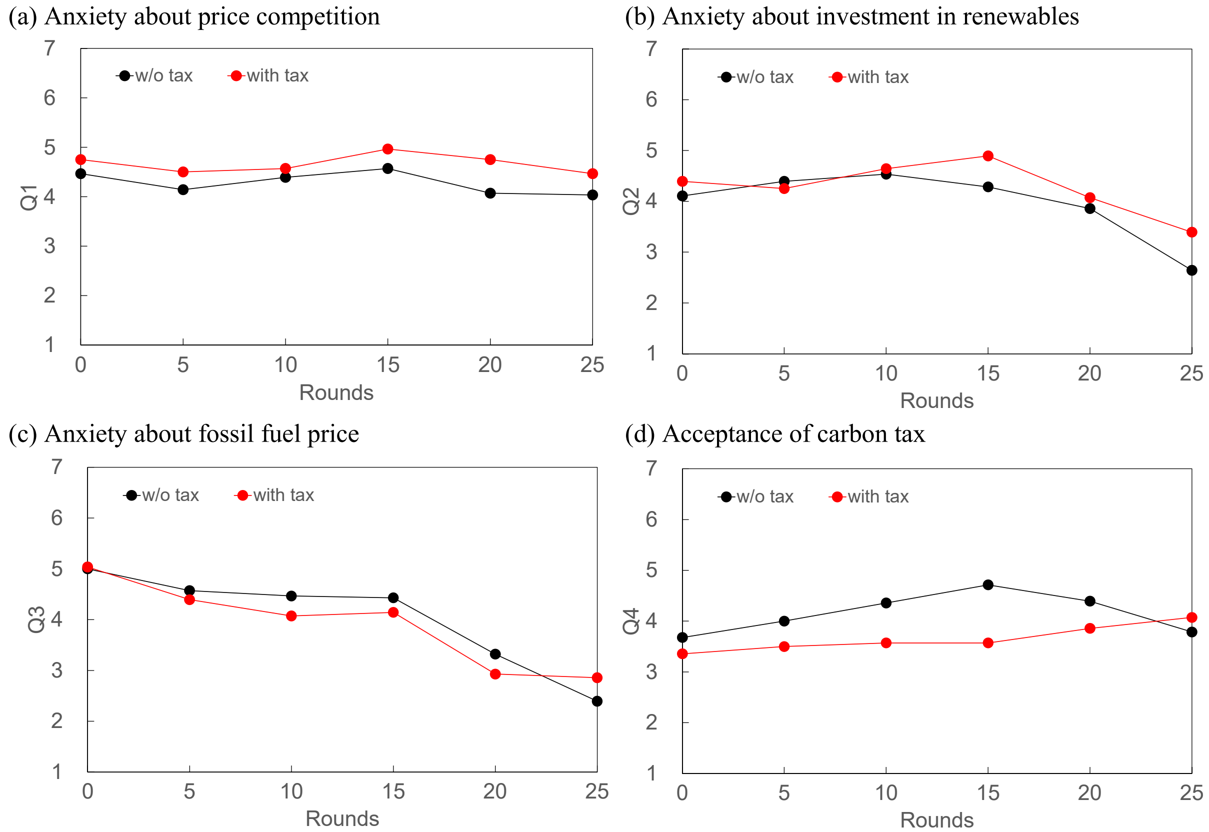
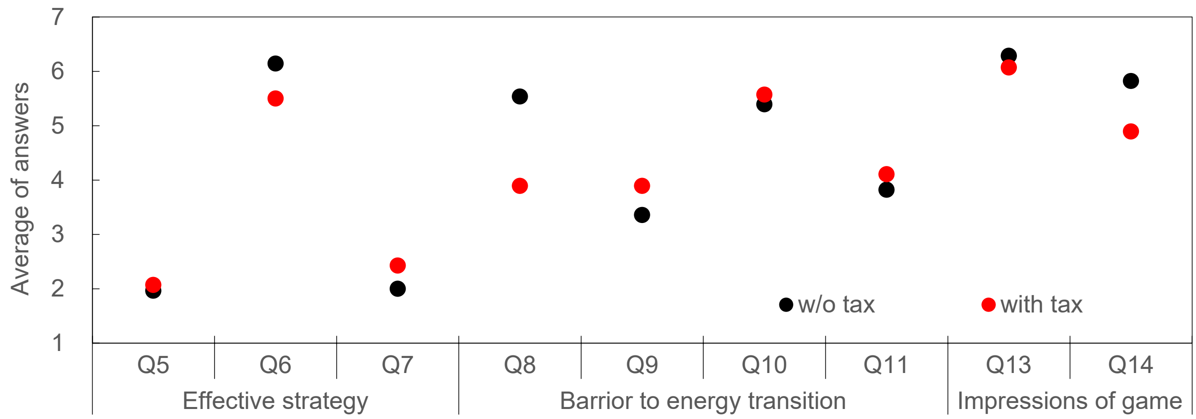


Figure 4: Answers to post-game questionnaire under conditions without and with carbon tax.



Therefore, the notice of carbon tax in advance cannot form the expectation that the energy transition is the best strategy without the knowledge of the return on investment in renewables and fossil fuel prices in the future. Even in the real market, energy companies will continue to use fossil fuels before taxation, and the effect of taxation appears to depend on the fossil fuel prices at that time.

Conclusions

This study investigated the effect of carbon tax on the selection of energy sources in competitive markets. In conclusion, the taxation to carbon emission can directly change the behavior of energy companies while the notation of taxation in advance cannot change their perception and behavior. According to these suggestions, the carbon tax can contribute to energy transition only when it is introduced as soon as possible, and the level of tax must be high enough to convince energy companies that the active investment in renewable is the optimal strategy. These implications are obtained in the first time by adopting the gaming simulation that can simultaneously shed light on both the objective and subjective aspecsts of real energy market.

This study also showed that the expeimental study of energy market can be held even under the epidemic of COVID-19 by utilizing the information technologies. By combining the web application and video communication systems, the experimental environment can be perfectly remoted. This achievement is useful even after the end of epidemic; this new environment can make the collection of participants and handling of experiments much easier and enables new types of research methods such as cloud experiments.

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