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Abstract

As a result of the Paris Agreement negotiated at the 21st Conference of the Parties, countries are beginning to reduce their greenhouse gas emissions. However, in Japan, too, environmental issues are complicated because of the political and economic interests of the parties involved. Consensus building can be difficult in democracies, and government initiatives are often inadequate. Accordingly, this study uses simulations to explore the possibility of solving environmental problems through firms' environmental strategies and market competition even if the government's environmental policies are inadequate.

This study built an agent-based model. In this model, consumer preferences and environmental awareness can change because of the influence of other consumers, firms, and society. The model assumes the presence not only of consumers who behave in an economically rational manner but also of consumers who behave in a humanly manner. This study examines the environmental strategies of firms and potential solutions to environmental problems in the face of such consumers and the inadequate environmental policies of the government.

The simulation results indicate that when consumers behave in a humanly manner, firms' environmental strategies in the market, as well as the transformation of consumers into environmentally oriented consumers, may become a win-win virtuous circle, which can effectively solve environmental problems, even when the government's environmental policies are inadequate. Introducing an environmental tax alone will change consumer awareness and society even if tax rates are set at an inadequate level. Therefore, if consumers behave in a humanly manner, environmental taxation with even an inadequate rate may lead to greater reductions in greenhouse gas emissions than standard economic theory would predict.

Keywords: computational economics, multi-agent simulation, environmental economics

JEL classification codes: C63

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1. Introduction

At the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change, held in Paris, France, in 2015, the Paris Agreement was adopted as a new international framework for reducing greenhouse gas emissions after 2020. In accordance with this agreement, countries worldwide are now working together to reduce greenhouse gas emissions. The Japanese government pledged to “reduce emission levels by 26% by 2030 compared with 2013.” Thereafter, in 2021, Japan raised its greenhouse gas reduction target to “reduce by 46% by 2030 as compared with the 2013 levels.”

How should we achieve our greenhouse gas reduction goals from an economics or a business administration perspective?

In economics, environmental problems are a prime example of market failure due to external diseconomies. It is usually the case that solutions to environmental problems are aimed at by imposing environmental taxes, such as Pigovian taxes, or by creating markets for the rights to emit greenhouse gases, such as the emissions trade market. However, environmental issues are complex in terms of the political and economic interests of the people involved. In democracies, consensus building is achieved through parliaments and other means; however, reaching a consensus is often difficult, and efforts to solve problems may not be implemented or may be inadequate. As of 2021, Japan is yet to introduce a carbon tax at a rate that will be sufficient to reduce greenhouse gas emissions by as much as 46%. We are experiencing not only market failures but also governmental failures as well as those of the people.

Environmental issues in business administration, unlike those in economics, can be viewed as problems of firms’ strategy of individual firms and competition within a given framework. From a corporate perspective, they include developing environmentally friendly products to increase sales, reducing costs for the sake of resolving environmental issues, or increasing the firm’s social reputation by addressing environmental issues such as the sustainable development goals.

Environmental issues are politically and economically complex. Even if a country is inadequate in terms of economic measures, firms must continue to operate, and it is important for the country to solve its environmental problems by improving its current performance. Accordingly, even if frameworks are inadequate at a national level, can environmental problems not be solved through firms’ environmental strategies and market competition? It is with this in mind that we conducted this study. For this study, a model was designed, built, and simulated for a firms’ environmental

strategy in the case of an inadequate national econometric framework, and several implications were obtained through the results. The simulation method used was an agent-based model. This is because consumer behavior is so complex, with changes and interactions, that it is impossible to accurately structure a model using mathematical analysis.

To conduct this study, we built our own model. Further, this study will outline the model we built.

The products that firms can sell are categorized into two types: conventional products that are bad for the environment and new, environmentally friendly products. Proactiveness to environmental problems differs from firm to firm, and we assume that the sales activities of each firm will be conducted such that the firm will sell either conventional products or environmentally friendly products, whichever sells better.

Consumers may purchase either conventional products that are bad for the environment or new, environmentally friendly products. Two types of consumers are assumed: old-style consumers and environmentally oriented consumers. As society becomes more and more familiar with environmentally friendly products, consumers will change from being old-style consumers to environmentally oriented consumers, and each consumer's preferences will also change because of the influence of society and other consumers. Each consumer has a different attitude toward environmental issues. The purchase behavior of each consumer in choosing between conventional and environmentally friendly products can be assumed to include various behavioral patterns, such as a lack of interest in environmental issues, rational behavior based on one's utility, and the humanly behavior of purchasing a different product in the future if dissatisfied with the original purchase.

Based on these hypothetical consumer behaviors, simulations were conducted to examine potential environmental strategies of firms when economic measures prove to be inadequate and to show the possibility of a win-win relationship between the environmental strategies of firms in the market and the environmental orientation of consumers.

The structure of this paper is as follows. Section 2 presents the framework of the model, definition of agents, and design of the simulation. In Section 3, the simulation results are presented and discussed. Section 4 presents the implications of the simulation results and summarizes the research findings.

2. The design of the simulation

2.1. Simulation overview

In this study, we use an agent-based model to simulate firms' environmental strategies. The agent-based model is a bottom-up modeling method that defines behavioral rules for each economic agent, such as firms or consumers (or households), places them in a computer-generated virtual market, and simulates them. Features of this method include the ability to represent a wide variety of agents and describe interactions between agents easily.

In the model we have constructed, consumer agents (2000 individuals), firm agents (100 individuals), and a government agent (1 individual) are placed in the simulation space (market). In this market, there are two types of goods (see Table 1) and trade in goods (both conventional products and environmentally friendly products) occurs when consumers purchase goods from firms. Conventional products generate external diseconomies, such as greenhouse gas emissions. Thus, from the perspective of environmental issues, it is desirable for society, as a whole, that environmentally friendly products are widely used.

Firms can adopt one of two strategies (see Table 2): a strategy of only selling conventional products (the Old-style Strategy) and another of only selling environmentally oriented products (the Environmentally Oriented Strategy), and each firm can decide which strategy to adopt. Additionally, individual firms can change the strategies they employ throughout the simulation period. It is possible to change from an Old-style Strategy to an Environmentally Oriented Strategy, and vice versa.

Table 1: Types of goods

	Types of goods	Explanation
(Goods B)	Conventional products	These are conventionally marketed products that are bad for the environment and have marginal external costs. These are sold by firms that use the Old-style Strategy.
(Goods G)	Environmentally friendly products	These new, environmentally friendly products are more expensive than conventional products but have no external costs. These products are sold by firms that have adopted an Environmentally Oriented Strategy.

Table 2: Firms' strategy

Firms' strategy	Explanation
Old-style Strategy	Strategy of only selling conventional products
Environmentally Oriented Strategy	Strategy of only selling environmentally friendly products

Table 3: Consumer categories and types of consumers

Types of consumers		Consumer categories
Old-style consumers (prefer conventional products) ↓ Environmentally oriented consumers (prefer environmentally friendly products)	←	Innovators Early Adopters Early Majority Late Majority Laggards

There are two types of consumers: old-style consumers, who prefer conventional products, and environmentally oriented consumers, who prefer environmentally friendly products. Basically, at the beginning of the simulation, all consumers are old-style consumers who prefer conventional products. Subsequently, as the spread of environmentally oriented products in society progresses, it is assumed that consumers will change from being old-style consumers to environmentally oriented consumers because of the influence of other consumers as well as society (see Table 3). The process of increasing the number of environmentally oriented consumers in society is based on the diffusion theory of innovation that was proposed in the work of Everett Rogers [1], which assumed five consumer categories: Innovators, Early Adopters, Early Majority, Late Majority, and Laggards. Each category to which a consumer can belong has a different ease of change from old-style consumers to environmentally oriented consumers.

Three patterns of consumer purchase behavior are assumed for modeling how consumers choose between conventional and environmentally friendly products (see table 4).

Table 4: Summary of rules for consumer purchase behavior

	Behavioral pattern	Explanation
(C01)	Behavioral patterns that	Little interest in environmental issues. When choosing

	show little interest in environmental issues	between conventional and environmentally friendly products during purchase, if the product customers prefer is sold nearby, they buy it; if not, they do not care much about other products.
(C02)	Rational behavior patterns	These consumers have their own utility values for conventional and environmentally friendly products. When choosing between conventional and environmentally friendly products, they will prioritize economic rationality based on personal preference, product price, and magnitude of utility.
(C03)	Humanly behavior patterns	When choosing between conventional and environmentally friendly products, if consumers are satisfied with the product they purchased the last time, they will continue to purchase the same product. However, if they are dissatisfied, they will try a different product the next time.

The government can use policies such as environmental taxes to reduce the incidence of external diseconomies (see table 5).

Table 5: Government policies

Government Policies	Explanation
Environmental tax	Excise taxes can be imposed on conventional products that are bad for the environment.
Environmental education	Environmental education has a probabilistic chance of changing consumer type from old-fashioned to environmentally oriented.

Using these conditions, we simulate the effectiveness of firms' environmental strategies that involve selling environmentally friendly products despite price increases and examine the simulation results.

2.2. Simulation space

The model framework, each agent's definition, and the parameter values are specifically defined as follows.

The simulation space type is a lattice model, and the size of the space is a two-dimensional torus measuring 50×50 in length and width, respectively; this space is regarded as the market. The agents placed in the simulation space are firm agents, consumer agents, and one government agent.

2.3. Goods traded

Each consumer agent purchases a good from a firm agent in each simulation step if the goods meet the required conditions. There are two types of goods: conventional products (Goods B) and environmentally friendly products (Goods G). Conventional products are environmentally unfriendly products that have been sold for a long time, and a marginal external cost of price 1 is incurred for each unit sold. Environmentally friendly products are new products that are environmentally beneficial and more expensive than conventional products; however, they do not incur any external costs. In the absence of government intervention, such as environmental taxes, conventional products are assumed to be traded in the market for price 1 per unit, and environmentally friendly products are traded for price 2 per unit.

2.4. Firm agents

Firm agents sell goods to consumers. At the beginning of the simulation, 100 individual firm agents are randomly placed in the simulation space. Individual firm agents do not move around within the space. Until the end of one simulation, each firm agent's position is fixed at its starting position from the beginning of the simulation. Each firm is given a variable value, called environmental proactiveness, which is determined by a uniform random number $Un [0,1)$ for each firm at the start of the simulation. The higher this value, the more proactive the firm will be toward helping the environment.

[Selecting a firms' strategy]

There are two types of corporate strategies: the Old-style Strategy of selling only conventional products and the Environmentally Oriented Strategy of selling only environmentally friendly products. Each firm can choose either strategy. Additionally, each firm can change its strategy

throughout the simulation. During every period (each step), each firm decides whether to keep or change the current strategy. The criteria for each firm's decision are as follows. As each firm can know the average sales per store (moving average) of conventional firms and average sales per store (moving average) of environmentally oriented firms, across society as a whole up to the previous period (previous step), each firm will make a probabilistic decision to switch to a strategy with higher average sales. Each firm's probabilistic decision is related to the magnitude of the value of its environmental proactiveness. Firms with a high level of environmental proactivity are more likely to switch from Old-style Strategies to Environmentally Oriented Strategies and, conversely, are less likely to switch from Environmentally Oriented Strategies to Old-style Strategies. Firms with a low level of environmental proactivity are less likely to switch from Old-style Strategies to Environmentally Oriented Strategies and, conversely, are more likely to switch from Environmentally Oriented Strategies to Old-style Strategies. Firms that adopt an Old-style Strategy and sell conventional products will be called conventional firms. Firms that adopt an Environmentally Oriented Strategy and sell environmentally friendly products will be called environmentally oriented firms.

[Firms' advertising]

Environmentally oriented firms can advertise to consumers to promote environmentally friendly products. Based on the diffusion theory of innovation [1], during every period, each firm can influence consumers by advertising to a specific category of consumers (Early Adopters in radius 5) that exist within its advertising horizon. Each firm will use this advertising to convert early adopters from old-style consumers into environmentally oriented consumers, with a certain probability of success (0.01). Early adopters who are old-style consumers are more likely than others to be influenced by the increasing number of environmentally oriented firms and change into environmentally oriented consumers.

[Firms' costs]

Cost functions are the same for each firm. In a conventional firm, there is no fixed cost for selling one unit of a conventional product, and the private marginal cost is set to 1. In an environmentally oriented firm, there is no fixed cost for selling one unit of environmentally friendly product, and the private marginal cost is set to 2.

2.5. Consumer agents

Each consumer agent purchases a good from a firm at each step of the simulation if it meets required conditions. At the beginning of the simulation, 2000 individual consumer agents are randomly placed in the simulation space. Each consumer agent moves around within the space by a small degree each period and selects the firms that exist within its purchasing horizon. The agent acts according to its consumer type (Conventional consumers, Environmentally Oriented consumers), consumer category (Innovators, Early Adopters, Early Majority, Late Majority, Laggards), and the rules of purchase behavior and purchases goods if the conditions are met.

[Consumer type]

There are two types of consumers: conventional consumers and environmentally oriented consumers. Each consumer begins the simulation as a conventional consumer preferring conventional products but changes into an environmentally oriented consumer as the diffusion of environmentally friendly products increases in society. The criteria of change depend on the consumer category to which each consumer belongs (Table 6). The type of consumer influences purchasing behavior. Conventional consumers prefer conventional products, while environmentally oriented consumers prefer environmentally friendly products.

[Consumer categories]

As the simulation progresses and society becomes more and more familiar with environmentally friendly products, consumers will change from being conventional consumers to environmentally oriented consumers. The change from conventional consumers to environmentally oriented consumers conforms to the diffusion theory of innovation [1]. Consumers assumed in this model are those in the five consumer categories in Table 6. Each consumer is probabilistically classified into one of the five categories at the beginning of the simulation. The criteria for the change from old-style to environmentally oriented consumers in each category are shown in Table 6.

Table 6: Consumer categories and consumer type change criteria as per the innovation diffusion theory

Consumer categories	Percentage	Explanation and consumer type change criteria
Innovators	2.5%	Innovators are adventurous people who are curious about new products. In this model, innovators automatically change into environmentally oriented consumers with a defined probability.
Early Adopters	13.5%	Early Adopters are opinion leaders in society. In this model, Early Adopters receive advertisement from firms and change from old-style to environmentally oriented consumers with a defined probability. Additionally, if they themselves are environmentally oriented consumers, Early Adopters can influence and encourage other Early Adopters within their word-of-mouth horizon to change into environmentally oriented consumers.
Early Majority	34.0%	Early Majority are consumers who are cautious about buying new products but who will buy items that are much talked about. In this model, a person may change into an environmentally oriented consumer because of the influence of Early Adopters within their word-of-mouth horizon who have already purchased environmentally friendly products.
Late Majority	34.0%	The Late Majority are consumers who are reluctant to buy new products and wait until they are sure that approximately half of the people around them have already purchased such products. In this model, if more than half of the consumers in the vicinity of their position in the space have already purchased an environmentally oriented product, and if close to half

		(approximately 45%) of the consumers in the entire market have changed into environmentally oriented consumers, they may change into environmentally oriented consumers.
Laggards	16.0%	Laggards are those in society who are the last to adopt innovation. These consumers are the most conservative, averse to changes, and skeptical about their transformation into environmentally oriented consumers. In this model, these consumers will not change into environmentally oriented consumers, except through the education provided by the government.

※ Consumer type change criteria were developed based on the literature [1].

[Utility of goods consumption]

Each consumer has a common level of satisfaction with conventional products (Goods B) and environmentally friendly products (Goods G). The satisfaction value is given to each consumer as a uniform random number $Un [0,1)$ at the start of the simulation. The magnitude of satisfaction in old-style consumers is the value of utility they receive when consuming one unit of each product. In environmentally oriented consumers, the utility value of one unit consumed differs between conventional and environmentally friendly products. For conventional products, the magnitude of satisfaction is directly related to the utility of consuming one unit of the conventional product. For environmentally friendly products, that satisfaction magnitude plus one unit of altruistic satisfaction is the value of utility when an environmentally oriented consumer consumes one unit of the environmentally friendly product. This is because the satisfaction of environmentally oriented consumers will increase because environmentally friendly products will not cause external diseconomies, such as greenhouse gas emissions.

[Consumer purchase behavior rules]

As consumer agents move from one place to another in the market during each period, they search for firms within their purchasing horizons and purchase goods from those firms if they meet their

requirements. Although there may be more than one firm within their purchasing horizon, old-style consumers prioritize purchasing conventional products from conventional firms. Conversely, environmentally oriented consumers give priority to purchasing environmentally friendly products from environmentally oriented firms. In this study, the following three patterns are used as rules for purchase behavior.

• **(C 01) Behavioral patterns that show little interest in environmental issues**

The purchase behavior of buying conventional and environmentally friendly products is relatively substituted, without much concern for environmental issues. This is a consumer behavior wherein people buy the products they prefer if they are available; if not, they buy other products.

- Environmentally oriented consumers will purchase one unit of an environmentally friendly product from an environmentally oriented firm if it is within their purchasing horizon. If there are no environmentally oriented firms but conventional firms in the scope of their purchasing vision, they will purchase one conventional product unit from among the conventional firms. If there are no firms within their purchasing horizon, they will not purchase anything.
- Old-style consumers will purchase one unit of a conventional product from a conventional firm if a conventional firm is within their purchasing horizon. If there are no conventional firms but environmentally oriented firms in their purchasing horizon, they will purchase one unit of environmentally friendly products from among the environmentally oriented firms. If there are no firms within their purchasing horizon, they will not purchase anything.

• **(C 02) Rational behavioral patterns**

This is a rational purchasing behavior where the utility and price of goods are evaluated and a purchase decision is made.

- Environmentally oriented consumers will purchase one unit of an environmentally friendly product from a suitable firm if environmentally oriented firms are within their purchasing horizon and if the consumers' utility for the environmentally oriented product exceeds its market price. Otherwise, if there are conventional firms within the scope of the purchasing

horizon, and if the consumers' utility for the conventional product exceeds the market price of the conventional product, they will purchase one unit of the conventional product from a suitable firm. If there are no firms within their purchasing horizon, they will not purchase anything.

- Old-style consumers will purchase one unit of the conventional product from a suitable firm if conventional firms are within their purchasing horizon and if the consumers' utility for the conventional product exceeds its market price. Otherwise, if there are environmentally oriented firms within the purchasing horizon, and if the consumers' utility for the environmentally friendly product exceeds the market price of the environmentally friendly product, they will purchase one unit of the environmentally friendly product from one of those firms. If there are no firms within their purchasing horizon, they will not purchase anything.

• **(C 03) Humanly behavioral patterns**

This is a purchase behavior that incorporates humanly behavior where if consumers are satisfied with the goods they purchased last time, they will prioritize purchasing the same goods again; however, if they are dissatisfied with the goods purchased last time, they will try other products the next time, if possible.

- If consumers have purchased an environmentally friendly product in the past and are satisfied that its utility is above the market price, or if consumers have purchased a conventional product in the past and are dissatisfied that its utility is below the market price, they will look for an environmentally oriented firm within their purchasing horizon. If there is an environmentally oriented firm present, they will purchase one unit of environmentally friendly product from one of the environmentally oriented firms. If no environmentally oriented firm is present, they will look for a conventional firm within their purchasing horizon. If a conventional firm is present, they will purchase one unit of conventional products from the conventional firm. If there are no firms within their purchasing horizon, they will not purchase anything.
- Consumers who purchased conventional products in the past and are satisfied that their utility is above the market price or consumers who purchased environmentally friendly products in the past and are dissatisfied that their utility is below the market price will look

for conventional firms within their purchasing horizon. They will purchase one unit of conventional products from a conventional firm if there are such firms. If there are no conventional firms present, they will look for environmentally oriented firms within their purchasing horizon and purchase one unit of environmentally oriented products. If there are no firms within their purchasing horizon, they will not purchase anything.

2.6 The government agent

At the beginning of the simulation, one government agent is generated. A government agent can implement the following policies, if necessary.

[Environmental taxes]

Conventional products are bad for the environment and generate external diseconomies, such as environmental pollution. To discourage the production of conventional products, the government agent can impose a specific tax on the sale of conventional products as an environmental tax. If an environmental tax is imposed, the marginal cost of conventional products will rise.

Environmental issues are complex in terms of the political and economic interests of the parties involved. In democracies, consensus building is achieved through parliaments and other means; however, reaching a consensus is often difficult, and efforts to solve problems may not be implemented or may be inadequate. Therefore, in this model, we also assume an environment tax with a tax rate that is applicable when environmental taxes alone are inadequate to solve environmental problems.

[Environmental education]

Through education, the government can probabilistically change consumers from old-style consumers to environmentally oriented consumers.

2.7. One-type goods model

As a benchmark, we assume a model similar to the classical economic model and simulate a market where only conventional products (Goods B) bad for the environment are sold and purchased.

Consumer agents (2000 individuals), firm agents (100 individuals), and a government agent (1 individual) are placed in the simulation space (market). In this model, consumers are assumed to be

exclusively old-style consumers who prefer conventional products and are assumed not to change into environmentally oriented consumers. Consumer purchase behavior is assumed to be (C 02) rational behavior patterns only. Firms will not change into environmentally oriented firms. In this setting, consumers will buy only the conventional product (B), and only one type of good (conventional goods (Goods B)) will be traded in the market. The government imposes environmental taxes at varying levels, whether sufficient or inadequate.

2.8 Two-type goods model

Consumer agents (2000 individuals), firm agents (100 individuals), and a government agent (1 individual) are placed in the simulation space (market). Two types of goods (conventional products (Goods B) and environmentally oriented products (Goods G) are traded in the market. All consumers are assumed to be old-style consumers at the beginning of the simulation. As per the diffusion theory of innovation, as environmentally friendly products become more prevalent, old-style consumers will become environmentally oriented. We will deal with three types of consumer purchase behavior: (C01) behavioral patterns that show little interest in environmental issues, (C02) rational behavior patterns, and (C03) humanly behavior patterns. Each firm is given a value of environmental proactiveness as an attribute. At the beginning of the simulation, each firm adopts the Old-style Strategy. During the simulation, each firm can change its strategy at its discretion, depending on the value of environmental proactiveness. However, to better analyze firms' environmental strategies, we created 2 firms out of 100 with a value of 1 for environmental proactiveness that adopted an Environmentally Oriented Strategy from the beginning of the simulation. These firms are proactive about environmental issues and are adamant about them even if it means disregarding profitability.

The simulation is conducted assuming that the government imposes no environmental tax or an inadequate level of environmental tax if one is imposed. This is because environmental issues are complex in terms of the interests of the parties involved, and it is difficult for a country to reach a consensus on a solution, which means that environmental taxes are rarely implemented at a necessary and sufficient level.

3. Simulation results and discussion

We simulated five models (see table 6). For the simulator, we used artisoc3.0 of KOZO KEIKAKU ENGINEERING Inc [2]. The results of the simulation are stochastic, and the results are different for each simulation. One simulation runs for 200 periods (200 steps), and the average result of 20 iterations is used for analysis.

Table 6: Models

Model	Model name
model 3.1	One-type goods model
model 3.2	Two-type goods (no environmental tax) model
model 3.3	Two-type goods (with inadequate environmental tax) model
model 3.4	Firms' environmental proactiveness in the two-type goods (with inadequate environmental tax) model
model 3.5	Environmental education in the two-type goods (with inadequate environmental tax) model

3.1. One-type goods model

We simulated a one-type goods model wherein the government imposed an environmental tax of $\{0.0, 0.3, 0.7, 1.0\}$ per unit of conventional products. As shown in Figure 1, imposing a larger environmental tax per unit of conventional product will reduce the level of environmental pollution. When no environmental tax is imposed ($t = 0.0$), about 400 conventional products (B) are sold every period; however, imposing an environmental tax reduces the level of sales. Because there was a marginal external cost of price 1 for each unit of the conventional product, the reduction in sales has curbed environmental pollution, which is consistent with economic theory. If a sufficient environmental tax is imposed ($t = 1.0$), no environmental pollution will occur. However, environmental issues are complex in terms of the interests of the parties involved. This makes it difficult for a country to reach a consensus on a solution, and environmental taxes are rarely implemented at a necessary and sufficient level. Therefore, in the two-type goods models in the next section, we will simulate a case wherein no environmental tax is imposed ($t = 0.0$) and a case wherein an environmental tax of 0.3 per unit of conventional product is imposed ($t = 0.3$), although this is inadequate.

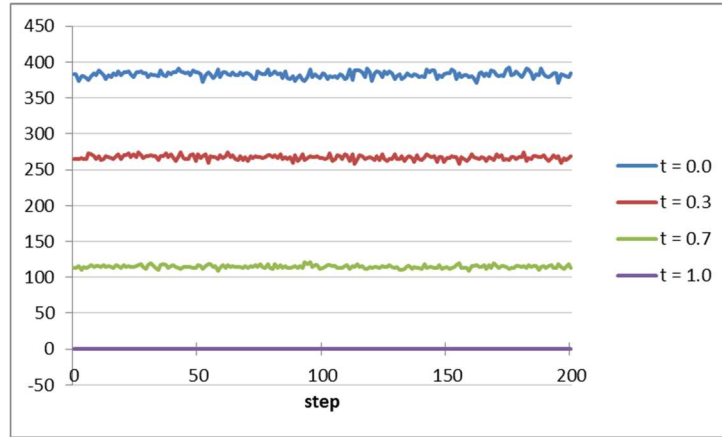


Fig.1: Effect of environmental taxation in the one-type goods model (vertical axis: magnitude of environmental pollution in each step)

3.2. Two-type goods (no environmental tax) model

This simulates a case in wherein the government does not implement any environmental tax ($t = 0.0$). The results of the simulation are shown in the Figures. Figure 2 shows the magnitude of environmental pollution (new) in each step according to each purchase behavior pattern shown by consumers (C01: behavioral patterns that show little interest in environmental issues, C02: rational behavior patterns, and C03: humanly behavior patterns). Figure 3 shows the cumulative environmental pollution. Figure 4 shows the percentage of environmentally oriented consumers in each step. Figure 5 shows the market share of environmentally friendly products in each step. These results show that no matter which consumer purchase behavior is used, the diffusion of environmentally friendly products increases as the steps progress amid the optimization behavior of firms' sales activities in the market, and new environmental pollution is controlled, as shown in Figure 2. Additionally, among the three patterns of consumer purchase behavior, rational behavior patterns (C02) are more likely to promote the use of environmentally friendly products and reduce environmental pollution than behavioral patterns that show little interest in environmental issues (C01) and humanly behavior patterns (C03). Behavioral patterns that are less concerned about environmental issues (C01), as well as humanly behavioral patterns (C03), will not stick to low-priced conventional products. This means that they are more likely to purchase environmentally oriented products (Goods G) and more likely to change into environmentally oriented consumers. As shown in the results of the one-type goods model in the previous section, an environmental tax

would be effective for rational behavior patterns (C02) after all.

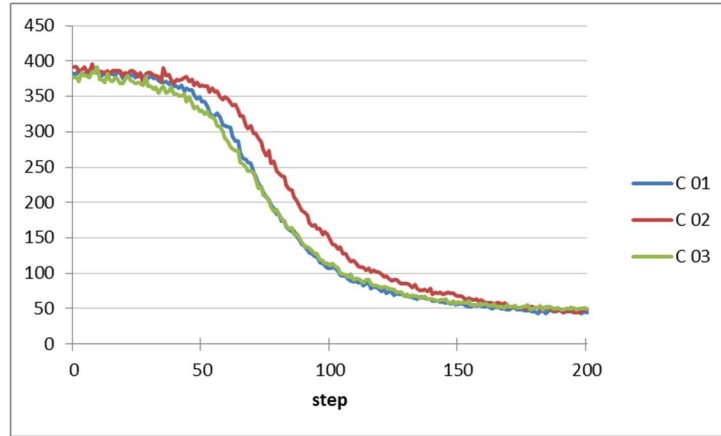


Fig. 2: Magnitude of environmental pollution (new) in the two-type goods (no environmental tax) model (vertical axis: magnitude of environmental pollution in each step)

C01: behavioral patterns that show little interest in environmental issues, C02: rational behavior patterns, and C03: humanly behavior patterns

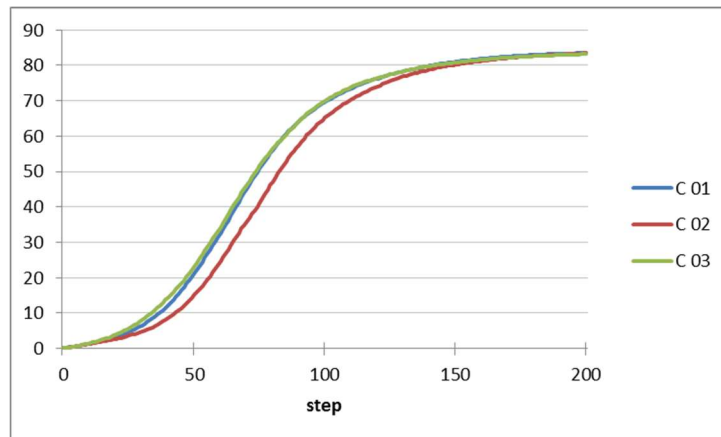


Fig. 3: Percentage of environmentally oriented consumers in the two-type goods (no environmental tax) model (%)

C01: behavioral patterns that show little interest in environmental issues, C02: rational behavior patterns, and C03: humanly behavior patterns

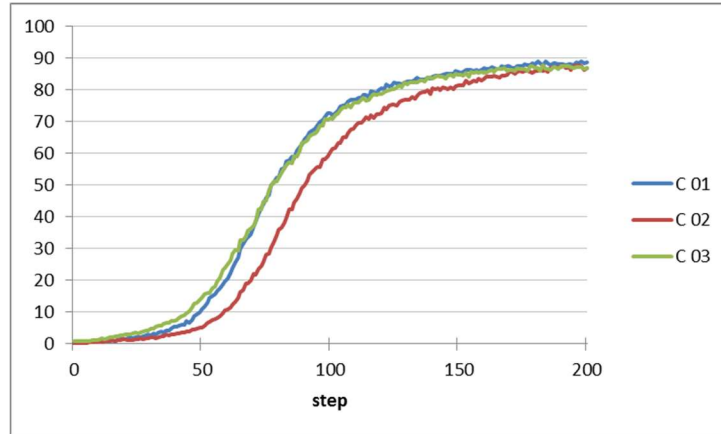


Fig. 4: Market share of environmentally friendly products (G) in the two-type goods (no environmental tax) model (%)

C01: behavioral patterns that show little interest in environmental issues, C02: rational behavior patterns, and C03: humanly behavior patterns

3.3. Two-type goods (with inadequate environmental tax) model

This simulates what would happen if the government imposed an environmental tax, albeit at an inadequate level. The simulation models a case wherein the government imposes an environmental tax of 0.3 per unit of conventional product ($t = 0.3$). In the real world, many such cases of inadequate taxation are considered likely to occur. Figure 5 shows the magnitude of environmental pollution (new) in each step according to the pattern of each consumer's purchase behavior (C01: behavioral patterns that show little interest in environmental issues, C02: rational behavior patterns, and C03: humanly behavior patterns). Figure 6 shows the cumulative environmental pollution. Figure 7 shows the percentage of environmentally oriented consumers in each step. Figure 8 shows the market share of environmentally friendly products in each step. As shown in Figure 5 and 6, the imposition of an environmental tax, although inadequate, significantly reduces environmental pollution when consumers follow rational behavior patterns (C02) or humanly behavior patterns (C03), compared with the case in the previous section wherein no environmental tax was imposed. This demonstrates that environmental taxes strongly contribute to pollution control, even though they still may be inadequate, when consumers follow rational behavior patterns (C02). Even in the case where consumers follow humanly behavior patterns (C03), the slope of the graph shows a steep decrease in pollution, suggesting that dissatisfaction with price increases because introducing environmental taxes affects the choice of products. As shown in Figure 7, the speed of change into environmentally

oriented consumers is faster when consumers follow humanly behavior patterns (C03), and as shown in Figure 8, among the three patterns of consumer purchase behavior, the environmentally friendly products are quickly diffused when consumers follow humanly behavior patterns (C03). This is because the tax, although set at an inadequate level, has led to an increase in the number of old-style consumers who are dissatisfied with conventional products and try to purchase environmentally friendly products. In the case of consumers with humanly behavior patterns (C03), introducing an environmental tax, even if inadequate, is a win-win virtuous circle between the firms' environmental strategies in the market and the change of consumers into environmentally oriented consumers.

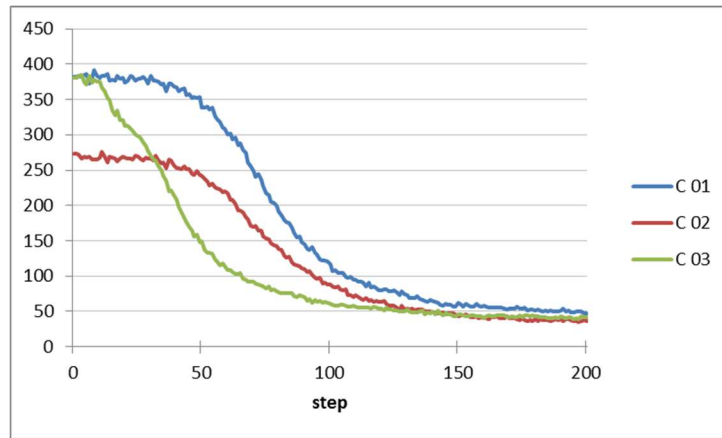


Fig. 5: Magnitude of environmental pollution (new) in the two-type goods (with inadequate environmental tax) model (vertical axis: magnitude of environmental pollution in each step)

C01: behavioral patterns that show little interest in environmental issues, C02: rational behavior patterns, and C03: humanly behavior patterns

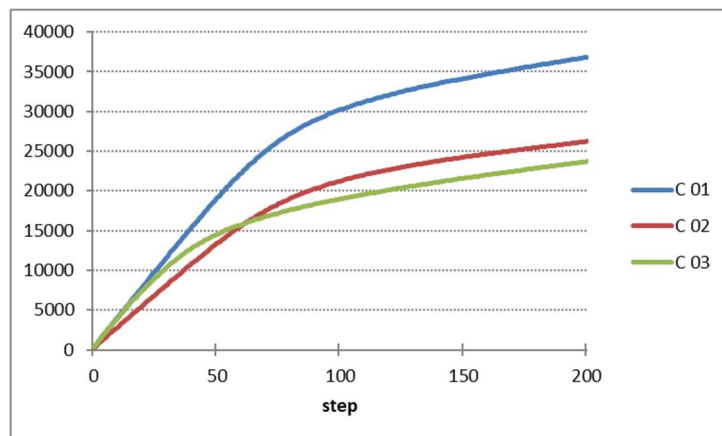


Fig. 6: Magnitude of environmental pollution (cumulative) in the two-type goods (with inadequate

environmental tax) model (vertical axis: cumulative environmental pollution)

C01: behavioral patterns that show little interest in environmental issues, C02: rational behavior patterns, and C03: humanly behavior patterns

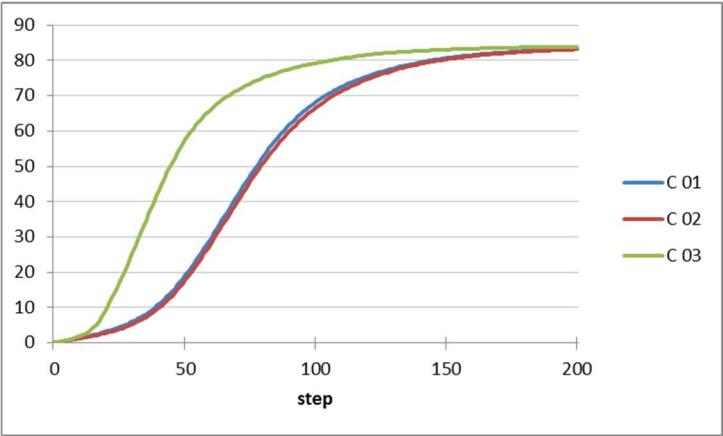


Fig. 7: Percentage of environmentally oriented consumers in the two-type goods (with inadequate environmental tax) model (%)

C01: behavioral patterns that show little interest in environmental issues, C02: rational behavior patterns, and C03: humanly behavior patterns

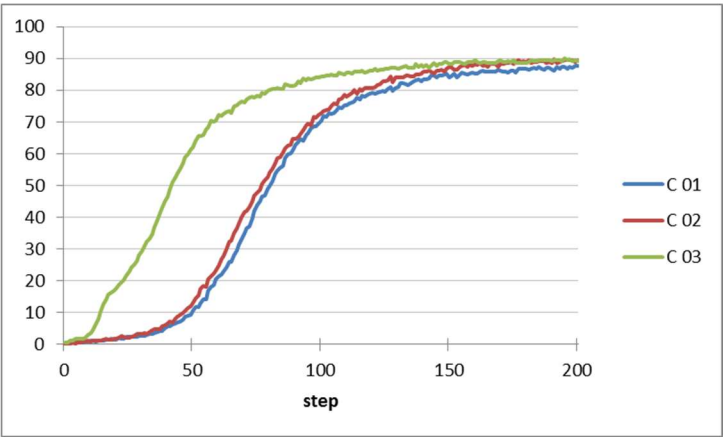


Fig. 8: Market share of environmentally friendly products (G) in the two-type goods (with inadequate environmental tax) model (%)

C01: behavioral patterns that show little interest in environmental issues, C02: rational behavior patterns, and C03: humanly behavior patterns

3.4 Firms' environmental proactiveness in the two-type goods (with inadequate environmental tax) model

We used the two-type goods model wherein the government imposes an environmental tax, albeit at an inadequate level ($t = 0.3$), to examine the impact of firms' environmental proactiveness.

Each firm has an attribute called environmental proactiveness. Firms with high levels of environmental proactiveness are more likely to switch from an Old-style Strategy to an Environmentally Oriented Strategy, while the reverse is less likely. Firms with low levels of environmental proactiveness are more likely to switch from an Environmentally Oriented Strategy to an Old-style Strategy, and vice versa. Of the 100 individual firms placed in the simulation space, environmental proactiveness is specified for 98 individuals by a uniform random number $Un [0,1)$ and for 2 individuals it is specified as 1. Firms with an environmental proactiveness level of 1 were assigned to Group 5, firms with an environmental proactiveness level of 0.5 and above but less than 1 were assigned to Group 4, and firms with an environmental proactiveness level less than 0.5 were assigned to Group 3. Firms belonging to Group 5 are fully dedicated to the environment, even if it is unprofitable. Firms belonging to Group 4 are more dedicated to the environment than the average firm, and firms belonging to Group 3 are less dedicated to the environment than the average firm.

Figures 9–11 show the average sales per store for each group of consumers according to their respective purchase behaviors (C01: behavioral patterns that show little interest in environmental issues, C02: rational behavior patterns, and C03: humanly behavior patterns). From these results, regardless of consumer purchasing behavior, the group of environmentally enthusiastic firms in Group 5 struggles with sluggish sales until environmentally friendly products begin the diffusion process. The group of environmentally unenthusiastic firms in Group 3 shows sluggish or diminishing sales as the environmentally friendly products become popular. Figure 11 also shows the possibility that the initial struggle period could be short if consumers in the market follow humanly behavior patterns (C03).

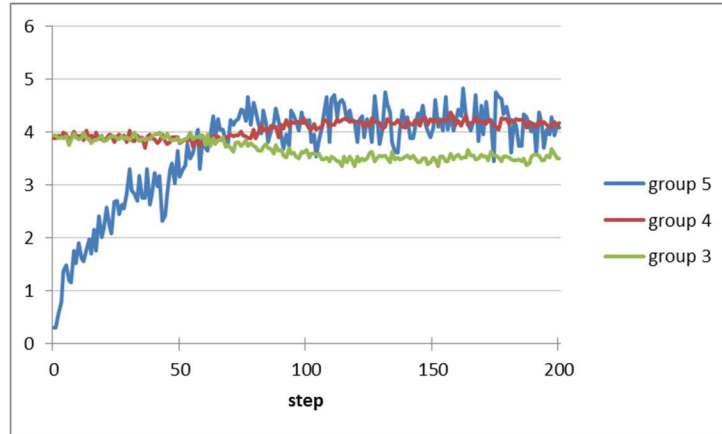


Fig. 9: Average sales per store by firm's environmental proactiveness when consumers are consumer type C01 (behavioral patterns that show little interest in environmental issues) in the two-type goods (with inadequate environmental tax) model

group 5: firms with an environmental proactiveness level of 1, group 4: firms with an environmental proactiveness level of 0.5 and above but less than 1, group 3: firms with an environmental proactiveness level less than 0.5

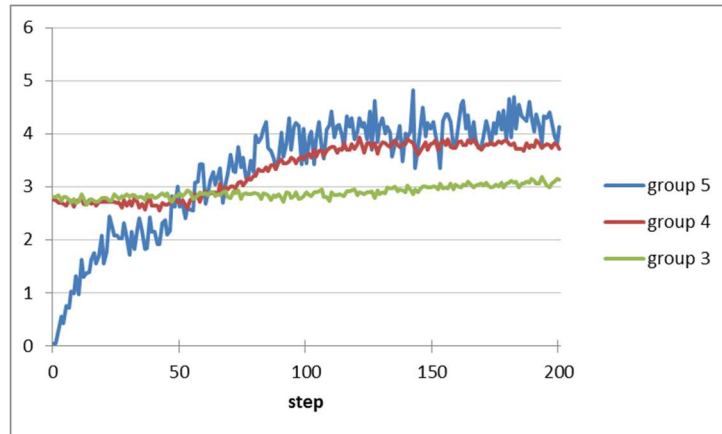


Fig. 10: Average sales per store by firm's environmental proactiveness when the consumer type is C02 (rational behavior patterns) in the two-type goods (with inadequate environmental tax) model

group 5: firms with an environmental proactiveness level of 1, group 4: firms with an environmental proactiveness level of 0.5 and above but less than 1, group 3: firms with an environmental proactiveness level less than 0.5

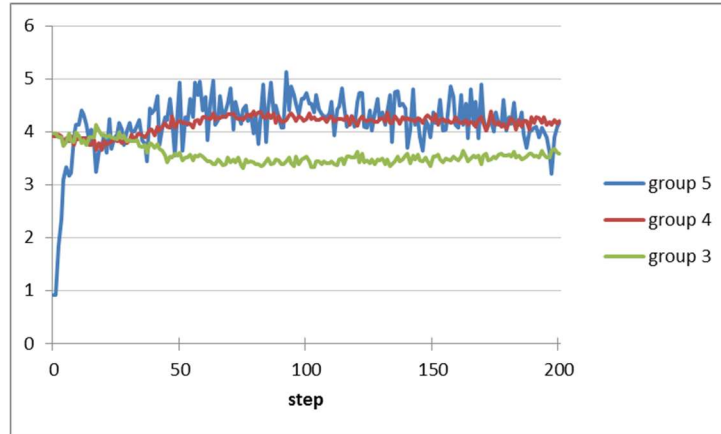


Fig.11: Average sales per store by firm's environmental product extreme when the consumer type is C03 (humanly behavior patterns) in the two-type goods (with inadequate environmental tax) model
group 5: firms with an environmental proactiveness level of 1, group 4: firms with an environmental proactiveness level of 0.5 and above but less than 1, group 3: firms with an environmental proactiveness level less than 0.5

3.5. Environmental education in the two-type goods (with inadequate environmental tax) model

Figures 12–14 show the results of simulations of cases wherein the government implements environmental education using the two-type goods model wherein the government imposes an environmental tax, albeit at an inadequate level. Figure 15 shows the cumulative environmental pollution. The results suggest that environmental education reduces environmental pollution, regardless of the consumer's purchasing behavior (C01: behavioral patterns that show little interest in environmental issues, C02: rational behavioral patterns, and C03: humanly behavioral patterns). It is often difficult to reach a consensus on solutions for environmental issues because of the complex interests of the parties involved. Thus, it may be necessary to change consumer preferences directly through education and awareness-raising activities and implement environmental measures along with environmental taxes albeit inadequate.

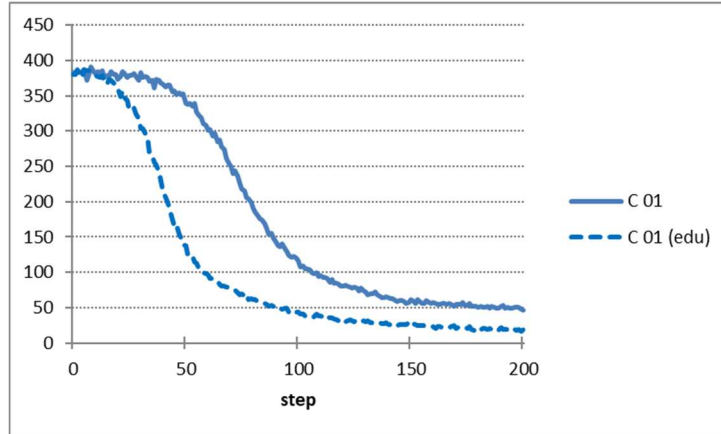


Fig. 12: Effect of environmental education for C01-type (little interest) consumers in the two-type goods (with inadequate environmental tax) model (vertical axis: magnitude of environmental pollution in each step)

C01: behavioral patterns that show little interest in environmental issues, C02 (edu): with environmental education

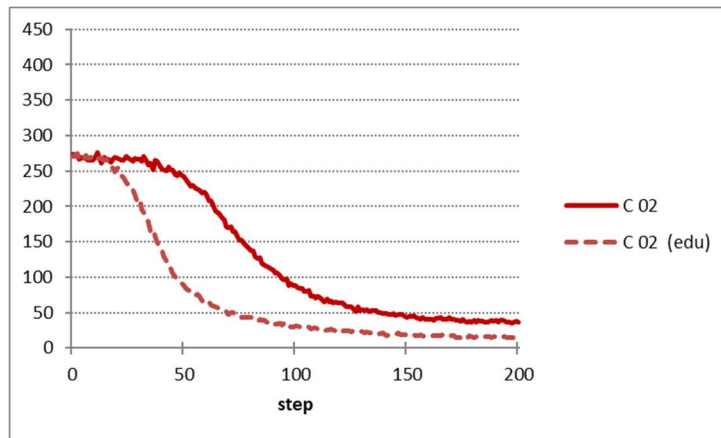


Fig. 13: Effect of environmental education for C02-type (rational) consumers in the two-type goods (with inadequate environmental tax) model (vertical axis: magnitude of environmental pollution in each step)

C02: rational behavioral patterns, C02 (edu): with environmental education

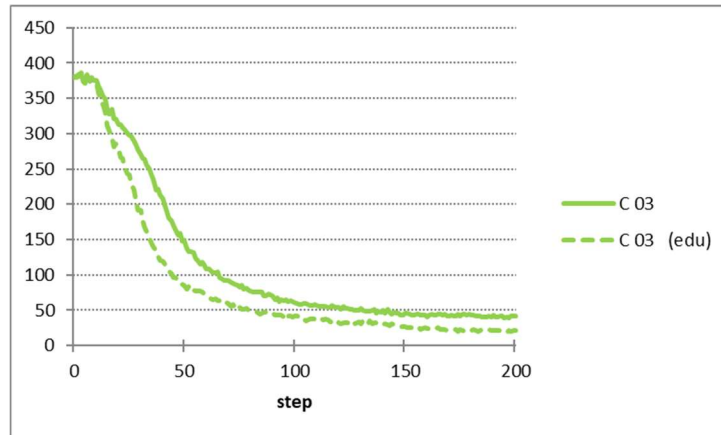


Fig. 14: Effect of environmental education for C03-type (humanly) consumers in the two-type goods (with inadequate environmental tax) model (vertical axis: magnitude of environmental pollution in each step)

C03: humanly behavioral patterns, C03(edu): with environmental education

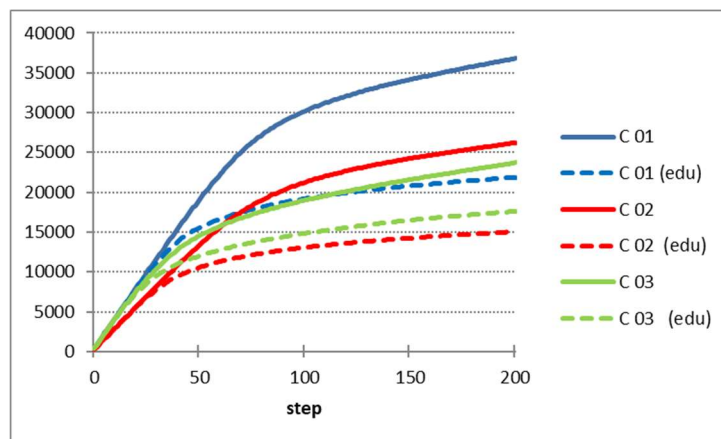


Fig. 15: Effect of environmental education for consumers in the two-type goods (with inadequate environmental tax) model (vertical axis: cumulative environmental pollution)

3.6. Additional considerations

The following considerations were obtained as a result of the analyses in Models 3.1-3.5.

- Environmental taxes appear to be an excellent solution to environmental problems.
- If consumers' purchase behavior follows either rational or humanly behavior, governments should introduce environmental taxes, even if they are of inadequate size.

- If consumers' purchasing behavior is humanly, introducing an environmental tax, even if inadequate, will be effective in helping to solve environmental problems by creating a win-win virtuous circle between the environmental strategies of firms in the market and changing consumers into environmentally oriented consumers.
- Even if an environmentally enthusiastic firm is quick to address environmental issues, it does not mean that its sales will increase, and its struggle period may be prolonged. However, if the market is such that consumers follow humanly behavior patterns, the initial period of struggle for environmentally enthusiastic firms may be short-lived.
- Environmental education and awareness-raising that directly affect consumers' consumption preferences are important and could compensate for the lack of measures that can be taken because of inadequate levels of environmental taxes.

As seen in the results of the one-type goods model (3.1), economics-based responses, such as environmental taxes, can have a powerful effect. However, in the real world, economics-based responses are not often implemented or are inadequate because environmental issues are complex in terms of the different interests of those involved, and consensus building takes time. It seems important to solve environmental problems, even if the framework for doing so is inadequate. Additionally, as seen in the results for the two-type goods (with inadequate environmental tax) model (3.3), environmental taxes are effective, even if inadequate, when consumers' purchase behaviors follow rational purchase behaviors.

If the purchasing behavior of consumers follows humanly behaviors, the environmental strategies of firms in the market and the change of consumers into environmentally oriented consumers will be a win-win cycle, which, amid competition in the market, may lead to the spread of environmentally oriented products and solving environmental problems. Additionally, the analysis of firms' environmental proactiveness (3.4) in the two-type goods (with inadequate environmental tax) model shows that the sales for firms that are reactive about environmental issues (Group 3) are lower than those of environmentally proactive firms (Group 4). However, further analysis is needed to determine whether a group of environmentally enthusiastic firms (Group 5) is desirable and what

level of environmental proactiveness is optimal. The simulation results suggest that the second group's environmental strategy may be more effective than environmentally enthusiastic firms. However, when consumers follow humanly behavior patterns, there is a possibility that environmentally proactive firms' strategies may be effective.

As shown in the results of the two-type goods (with inadequate environmental tax) model, environmental education (3.5) is important, and if economic policies such as environmental taxes are inadequate, it is desirable that education and awareness-raising should also be implemented.

Furthermore, the following implications can be drawn from these results.

- If consumers follow humanly behavior patterns, environmental taxes, even if inadequate, may lead to greater reductions in greenhouse gas emissions than standard economic theory would predict.

Consumers often act in a humanly way, not necessarily in an economically rational way. When consumers follow humanly behavior patterns, their preferences (tastes) and environmental awareness are easily influenced and changed by other consumers, firms, and society. As part of humanly behavior, consumers may be disappointed with a product they purchased and will try a different product the next time. Thus, if consumers follow humanly behavior patterns, even inadequate environmental taxes may lead to greater reductions in greenhouse gas emissions than standard economic theory would predict. Even in such cases, if combined with environmental education and awareness-raising, it would go a long way toward solving environmental problems.

4. Conclusion

In this study, we developed an agent-based model to analyze the effects of environmental measures in response to several consumer behavioral patterns and firms' environmental strategies in cases where inadequate economics-based environmental measures were put in place.

In the agent-based model we constructed, we placed consumer agents, firm agents, and a government agent in a simulation space (market). In the market, conventional and environmentally oriented products were traded. Considering that conventional products generate environmental pollution, it is hoped that environmentally friendly products will become more popular. There are

two types of consumers: old-style consumers and environmentally oriented consumers. As the diffusion of environmentally friendly products progresses, consumers will change from old-style consumers to environmentally oriented consumers in accordance with innovation theory. Consumers are influenced by other consumers, firms, and society, and their preferences (tastes) may change. We assumed three consumer behavioral patterns: those that show little interest in environmental issues, those that are rational, and those that are humanly. Firms can choose between an Old-style Strategy and an Environmentally Oriented Strategy. Governments can use policies such as environmental taxes, even if they are set at inadequate levels, to reduce external diseconomies.

After analyzing these models, the following implications were obtained. Consumers not only act in an economically rational way but also in a humanly way. Therefore, even at inadequate rates, the introduction of environmental taxes could change consumer attitudes and society, leading to greater reductions in greenhouse gas emissions than standard economic theory would predict.

- Environmental taxes appear to be an excellent solution to environmental problems.
- If consumers' purchase behavior follows either rational or humanly behavior, governments should introduce environmental taxes, even if they are of inadequate size.
- If consumers' purchasing behavior is humanly, the introduction of an environmental tax, even if inadequate, will be effective in solving environmental problems by creating a win-win virtuous circle between the environmental strategies of firms in the market and changing consumers into environmentally oriented consumers.
- Even if an environmentally enthusiastic firm is quick to address environmental issues, it does not mean that its sales will increase, and its struggle period may be prolonged. However, if the market is such that consumers follow humanly behavior patterns, the initial period of struggle for environmentally enthusiastic firms may be short-lived.
- Environmental education and awareness-raising that directly affect consumers' consumption preferences are important and could compensate for the lack of measures that can be taken as a result of inadequate environmental taxes.

- If consumers follow humanly behavioral patterns, environmental taxes, even with inadequate tax rates, may lead to greater reductions in greenhouse gas emissions than standard economic theory would predict.

The analysis of this model was done by comparing the average results of repeated simulations. Following the literature, it will be necessary for future studies to treat any further simulation results in a probabilistic manner [3].

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