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Greenhouse gas emission liberalization considering the heterogeneity of companies and interactions between technology adoption strategies and business strategies

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Abstract

Corporations are the main entities that trade in carbon reduction and allowances. Due to the heterogeneity of the initial inventory of technologies, the reduction costs of the companies are different, and as a result, the reduction activities and the carbon price dynamics are different. Many studies related to the ETS link pay little attention to firms' behaviors, especially the interactions between firms' technology adoption strategies and their subsidy trading strategies. Furthermore, whether the ETS link can reduce carbon emissions with lower system costs has not yet been sufficiently investigated. This study develops an agent-based model (ABM) to investigate the linkage effect of two emissions trading systems, taking into account firm heterogeneities and interactions between technology adoption strategies and allowance trading strategies. This model considers two GHG emissions trading systems, each of which includes energy service providers that are heterogeneous in scale of production and initial inventory of technologies (thus with different abatement costs), and attempts to determine, by making a decision, the total cost minimize for a given output.

Keywords: greenhouse gas emissions, technology adoption, business strategies, factor modeling
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1 Introduction

Globalization is a phenomenon that affects human life from various economic, political and social aspects. The phenomenon of globalization creates access to foreign capital, trade and, as a result, faster growth of developing and developed countries. Developed countries can develop their production process by employing cheap labor from developing countries, and developing countries can achieve development through access to advanced technology that consumes less energy. On the other hand, trade liberalization leads to the transfer of capital and as a result economic

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growth and ultimately increase in welfare. But this increase in economic prosperity has many environmental effects in every country [4]. Energy is considered a fundamental factor in the economic life of any country, and the economic development of any country requires the acquisition and use of energy resources. Considering that most of the energy consumed in the world is of the fossil energy type, its excessive consumption also causes environmental problems such as the emission of carbon dioxide gas. This has led to an increase in awareness among economists and policymakers about the reduction of environmental quality and its destructive effects on climate change since the 1960s [10]. Because after the Second World War, the attention of many currently developing countries was mainly focused on the process of industrialization, and no attention was paid to environmental issues and management of the environment and natural resources. In fact, developing countries have been unable to fulfill their role as suppliers of public goods and have faced failure in compensating for market failures, especially in the field of attention to environmental protection and preventing its destruction and pollution. Following the environmental problems, the impact of global warnings on the economy of different countries and the global economy has been the focus of many researchers since the 1990s, and many international organizations at the global level with the aim of reducing the harmful effects of global warnings through agreement Intra-governmental letters or restrictions and coercion have been formed. The Kyoto Agreement is one such agreement that was signed in 1997 after a series of extensive and comprehensive negotiations. The main goal of this agreement is to reduce the amount of greenhouse gas emissions that cause climate change. Also, several studies were conducted on the impact of energy consumption on economic growth and on environmental degradation and greenhouse gas emissions. Based on these studies, there is a lot of evidence that there is a positive relationship between energy consumption and the improvement of macroeconomic variables. Also, these studies remind the role of improving macroeconomic variables due to the growth of energy consumption on the spread of pollution. Therefore, it seems that economic growth and development followed by an increasing increase in energy consumption will increase the emission of greenhouse gases. The occurrence of this phenomenon is different in different countries, so that in some countries, in a long period of time, the growth and development of technology can reduce pollution, while such a situation will not exist in all countries. It can be assumed that economic growth causes more consumption of energy resources and as a result increases the emission of carbon dioxide gas.

The increase in greenhouse gas emissions and climate change in the last two decades has become one of the major international concerns. After the Second World War, the attention of many developing and advanced industrial countries was mainly focused on the process of industrialization and not much attention was paid to environmental issues and natural resources. Since the 1990s, under the influence of global warnings and the attention of many researchers, several global organizations have been formed with the aim of reducing the harmful effects of global warnings through intergovernmental agreements or establishing domestic restrictions and requirements. The Kyoto Agreement is one of these agreements that was signed in 1997 after a series of extensive and comprehensive negotiations. The main goal of these agreements is to reduce the amount of greenhouse gas emissions that cause climate change. According to this agreement, the Iranian government is also required to reduce the total emission of carbon dioxide gas. One of the basic and significant issues in recent decades has been the issue of economic growth and maintaining environmental quality in human societies. The study of the relationship between economic development and the environment began in the 1970s with studies on the limits of growth and sustainability. In this decade, the attention of environmental economics was focused on economic growth, and except for the factors of labor and capital, natural resources were also included in the function of production, and its main goal was the best optimal path of economic growth, which according to the assumption of the constant reserve of non-renewable resources, to It is achieved [8].

After that, the relationship between economic growth and environmental pollution was extensively analyzed statistically. Some researchers, including Kolstad and Krautkraemer [6], believe that economic growth and increased production require more use of natural resources and energy, especially fossil fuels, which in turn leads to environmental degradation. Therefore, this group of researchers believe that excessive economic growth beyond the capacity of the environment should be abandoned in order to prevent ecological disaster in the future. On the other hand, some other researchers not only do not consider economic growth as a cause of environmental degradation, but consider it necessary to maintain and improve the quality of the environment in the long run. Meadows et al. [2] argue that economic growth is necessary to maintain and improve the quality of the environment in the long term before it is a threat to the environment. This type of win-win situation is based on the belief that economic growth leads to an increase in per capita income, which can lead to poverty reduction and a clean environment [12]. While most studies have focused on economic development and the environment, a limited number of studies have addressed the effect of financial development on environmental preferences. Meanwhile, it seems that financial development can have an important and effective role in reducing the emission of pollutants. Financial development includes the factors, policies and institutions that cause communication with intermediaries and efficient financial markets and wide access to capital and financial services [14]. Financial intermediaries can improve the quality of the environment through access to environmentally friendly technologies. Also, the developed financial sector can act as an important driver in increasing economic growth through the optimal allocation of financial resources, which can reduce environmental destruction at higher income levels. But on the other hand, some researchers such as Bernard and Jensen [1] state that further development of the financial sector may improve economic growth, but it can increase industrial pollution and increase environmental destruction [12]. In the late 1970s, environmental concerns began to be included in trade analyses, and in the 1980s, they were considered important topics in international negotiations. The increase in trade affects the amount of pollution emissions in two ways: through the increase in emissions caused by international transport and through the transfer of emissions from the importing country to the exporting country. While the increase in the production of polluting goods in the exporting countries leads to the possibility of an increase in pollution in these countries.

This study develops an agent-based model (ABM) to investigate the effect of the GHG emissions nexus by considering firm heterogeneities and interactions between technology adoption strategies and subsidy trading strategies. This model considers greenhouse gas emissions, each of which includes energy service providers that are heterogeneous in scale of production and initial inventory of technologies (and thus with different abatement costs), and attempts to estimate costs by decision making. minimize the total for a given output.

2 Research methodology

Basis factor modeling as one of the simulation techniques of complex adaptive systems is placed next to dynamic and discrete event system techniques. Emphasis on the modeling of the behavior of non-homogeneous agents and the occurrence of emergent behaviors are two important capabilities that separate agent models from the simulation approaches of discrete events and dynamic systems. Because of its high flexibility, factor-based modeling has had many applications in various branches of economics. In the field of economics, this method has been widely used to model the behavior of customers in the market and the marketing process, the behavior of actors in the stock market, the supply chain, and the distribution systems of goods and services. In recent years, the application of factor-based modeling in the field of macroeconomics has also expanded a lot, which is known as factor-based computational economics or factor-based computational economics (ACE).

In agent-based modeling, the communication of agents can be modeled in the form of social networks, organizations and assemblies, and in these models, when the initial conditions are clarified, other events are created only by transactions between agents. Therefore, in these models, instead of focusing on the equilibrium positions of a system, attention is paid to the development process of the system over time. The goal of this approach is to gain a better and deeper understanding of the overall picture of a system. The advantage of focusing on the process instead of equilibrium is that modeling can be done even if equilibriums are inaccessible or do not exist. Factor-based modeling can be a good supplement for other modeling methods. This is because the assumptions and parameters of factor-based models can be linked to other methods. When the behavioral rules, processes and behavioral parameters of the agent-based model are built based on the results of other models, these models can lead to good results.

The model building stage is a software process and its purpose is to create an executable version of the model that can be implemented computationally. This calculation process should be consistent with the conceptual model designed in the previous step. There are two methods for this purpose. The first method is to write the model in general programming languages such as Python. The second method is to use specialized agent-based modeling software such as Anylogic. Of course, for factor-based modeling, various software such as Excel software in simple levels and multipurpose mathematical computing systems such as MATLAB are also used.

The next step is to implement the conceptual model in the software environment. Building the model is a software process and its purpose is to create an executive version of the model that can be implemented computationally and should be consistent with the conceptual model designed in the previous step. After the model is made, the steps of making the model should be carefully reviewed and the validity of the model should be measured. These two processes are called review and validation. The review process is designed to check the compliance of the built computer model with the conceptual model. Validation of the model is also done in order to match the results of the model with the real data. In order to validate the model, it is necessary to run the built model in different intervals and compare its results with real data. If statistical data is used in the model, statistical tests can also be used to validate the model. After the model has been reviewed and validated, it can be used as an analytical tool.

3 Research findings

Suppose there are N heterogeneous factors in any economic system. Let $y^t_{i,n}$ denote the capacity of factor $(n = 1, 2, ...N)$ that is newly installed $(i = 1, 2, 3)$ at time t and then the total installed capacity of technology i at the time

t. As $C_{i,n}^{t}$ can be calculated as

$$C_{i,n}^{t}=\begin{cases}\sum_{j=t-\tau_i}^{t} y_{i,n}^{j}, & t>\tau_i\\ \sum_{j=1}^{t} y_{i,n}^{j}+\frac{\tau_i-t}{\tau_i}C_{i,n}^{0}, & t\leq\tau_i\end{cases} \tag{3.1}$$

where $i=1,2,3$ represents existing, incremental and revolutionary technology respectively. τ_i represents the plant life of technology i. $C_{i,n}^{0}$ represents the initial capacities of factor n of technology i. In each decision interval, agent n's cumulative experience with technology i at time t can be expressed as its cumulative production with technology i at time t, as shown in the equation below.

$$E_{i,n}^{t}=E_{i,n}^{0}+\sum_{j=1}^{t} x_{i,n}^{j} \tag{3.2}$$

where $E_{i,n}^{t}$ represents the cumulative experience of agent n with technology i at time t. $E_{i,n}^{0}$ represents the initial experience of agent n with technology i. $x_{i,n}^{t}$ represents the production of factor n using technology i at time j. The unit investment cost of existing technology is assumed to be constant as it matures, and the costs of incremental and revolutionary technologies decrease with technological learning, as shown in the equation below.

$$CF_{i,n}^{t}=\begin{cases}CF_{i,n}^{0}, & i=1\\ CF_{i,n}^{0}\cdot\left(E_{i,n}^{t-1}\right)^{-b_i}, & i=2,3\end{cases} \tag{3.3}$$

where $CF_{i,n}^{t}$ represents the unit investment cost of agent n for technology i at time t. $CF_{i,n}^{0}$ represents the initial unit investment cost of factor n for technology i. $1-2-b_i$ is the learning rate of technology i, which represents the percentage reduction in future unit investment cost for each doubling of experience. $2-b_i$ is the ratio of the process, which indicates the speed of learning. The total consumption of factor resource n at time t is a function of its production, which is obtained by the equation.

$$R_{n}^{t}=\sum_{i=1}^{3}\frac{x_{i,n}^{t}}{\eta_i} \tag{3.4}$$

here, R_{n}^{t} represents the total consumption of factor resource n at time t and η_i shows the efficiency of technology i. The cumulative resource consumption of factor n with time t, denoted by R_{n}^{t}, can be represented as

$$\overline{R}_{n}^{t}=\sum_{j=1}^{t} R_{n}^{j} \tag{3.5}$$

As shown in Eq., the unit resource extraction cost, denoted by CE_{n}^{tnt}, is assumed to be linearly correlated with the cumulative resource consumption of agent n. We obtained the simulation of cumulative resource consumption of factor n using MATLAB software as follows:

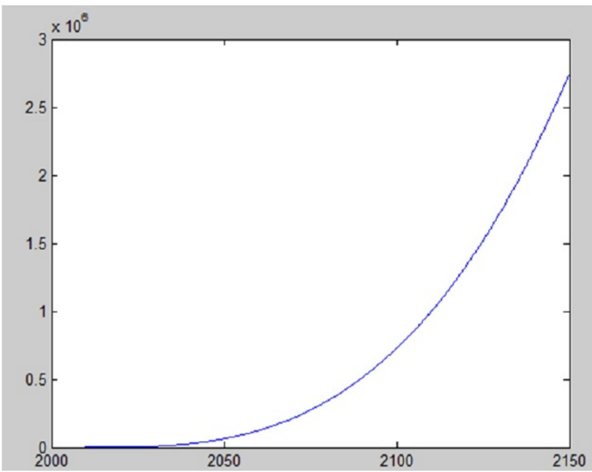

Figure 1: Cumulative resource consumption simulation

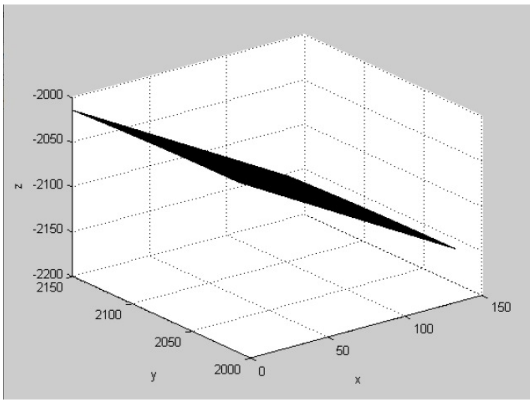

Figure 2: External demand over time with annual growth rate

Demand is exogenous and increases over time at an annual growth rate, as shown in the equation below, simulating the demand equation as follows:

$$D^t = D^0(1+\alpha)^t \tag{3.6}$$

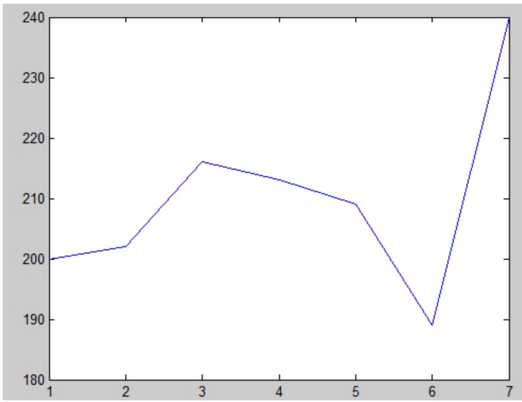

Figure 3: External demand over time with annual growth rate

Agents are assumed to have heterogeneous scales of production or market share. Let w_n denote the market share of agent n in his system. In each decision interval, agents simultaneously make technology adoption decisions. Without allowance trading, each agent optimizes its technology adoption with the following model:

$$\min \sum_{i=1}^{3} \frac{1}{(1+\delta_r)^t} CF_{i,n}^t \cdot y_{i,n}^t + \frac{1}{(1+\delta_r)^t} CE_n^t \cdot R_n^t + \sum_{i=1}^{3} \frac{1}{(1+\delta_r)^t} COM_i \cdot x_{i,n}^t \tag{3.7}$$

$$s.t. \qquad w_n D^t \le \sum_{i=1}^{3} x_{i,n}^t \tag{3.8}$$

$$x_{i,n}^t \le C_{i,n}^t, \qquad \forall i \tag{3.9}$$

$$x_{i,n}^t \ge 0, \qquad \forall i \tag{3.10}$$

$$y_{i,n}^t \ge 0, \qquad \forall i \tag{3.11}$$

$$\sum_{i=1}^{3} \frac{\lambda_i}{\eta_i} x_{i,n}^t \le Cap_n^t \tag{3.12}$$

δ_r represents the discount rate. COM_i represents the cost of operating and maintaining the technology. λ_i represents the carbon emission factor of technology i. Cap_n^t represents n-factor carbohydrate.

The objective function is the total cost, including investment cost, resource extraction cost, and operation and maintenance (OM) cost. Constraint (3.8) indicates that the production of a factor must satisfy its market share of the total demand. Constraint (3.9) indicates that the production of an agent cannot exceed its installed technological capacities. Constraints (3.10) and (3.11) show that the decision variables cannot be negative. Constraint (3.12) indicates that the emission of an agent cannot exceed its carbon ceiling

a) Before connecting the two emissions trading systems. With fixed initial allowances, an agent can sell their excess allowances for a profit or buy allowances from others if they want to spread more. Therefore, for factor n at time t, without the link of the emissions trading system, its optimization model can be written in writing.

$$\min \sum_{i=1}^{3} \frac{1}{(1+\delta_r)^t} CF_{i,n}^t \cdot y_{i,n}^t + \frac{1}{(1+\delta_r)^t} CE_n^t \cdot R_n^t + \sum_{i=1}^{3} \frac{1}{(1+\delta_r)^t} COM_i \cdot x_{i,n}^t - \frac{1}{(1+\delta_r)^t} p^t Q_n^t \tag{3.13}$$

$$s.t. \qquad \sum_{i=1}^{3} \frac{\lambda_i}{\eta_i} x_{i,n}^t + Q_n^t \leq Cap_n^t \tag{3.14}$$

and in constraints (3.8)–(3.11), p_t represents the carbon price at time t. Q_n^t represents the trading volume of agent n at time t, $Q_n^t > 0$ indicates seller n and $Q_n^t < 0$ indicates agent n is buyer. The objective function is the total cost after the allowance transaction. Constraint (3.14) shows that an agent can make a profit if it controls its carbon emissions below the carbon ceiling, or it can purchase additional reserves to emit more.

b) After connecting the two emissions trading systems. In general, the link between the greenhouse gas emission trading system can be divided into two categories: direct link and indirect link. With a direct link, one system recognizes the other's privileges for compliance, and permissions can be exchanged directly between systems. In general, direct links can be one-way (one-way) or two-way (two-way or multi-way) [5]. With the age of indirect linkage, the supply and demand of subsidies in one system may affect the supply and demand of subsidies in another system through linkage with a common system. This study examines the status of bilateral direct grafting. With a direct two-way link, each agent can buy or sell allowances not only in the internal system but also in their connected external system. The volume of transactions Q_n^t can be expressed as $Q_{n,Intra}^t + Q_{n,Inter}^t$, where $Q_{n,Intra}^t$ represents the volume of intra-system transactions and $Q_{n,Inter}^t$ represents the volume of inter-system transactions. Therefore, for factor n at time t, after linking the greenhouse gas emissions trading system, its optimization model becomes

$$\min \sum_{i=1}^{3} \frac{1}{(1+\delta_r)^t} CF_{i,n}^t \cdot y_{i,n}^t + \frac{1}{(1+\delta_r)^t} CE_n^t \cdot R_n^t + \sum_{i=1}^{3} \frac{1}{(1+\delta_r)^t} COM_i \cdot x_{i,n}^t - \frac{1}{(1+\delta_r)^t} p^t (Q_{n,Intra}^t + Q_{n,Inter}^t) \tag{3.15}$$

$$s.t. \qquad \sum_{i=1}^{3} \frac{\lambda_i}{\eta_i} x_{i,n}^t + Q_{n,Intra}^t + Q_{n,Inter}^t \leq Cap_n^t \tag{3.16}$$

And constraints (3.8)–(3.11) is the objective function of the total cost after linking the emissions trading system. Constraint (3.16) indicates that an agent can buy or sell allowances not only in its domestic emissions trading system but also in the related foreign emissions trading system. Although many contributions have been made in analyzing the impact of the carbon emission trading mechanism on technology adoption (see, for example, Cong and Wei [3]; Tang et al. [13]; Zhao et al. [15]; Liu et al. [7]), most studies ignore the dynamics of the carbon price. The carbon price changes with agents' marginal abatement costs and affects agents' adoption strategies. For example, if the price of carbon exceeds an agent's marginal abatement cost, the agent does not buy any aid, but instead makes its own carbon abatement. If the carbon price is less than an agent's marginal abatement cost, the agent will not sell any allowances. In our ABM, the dynamic carbon price is derived based on agents' WTP. WTP calculates the lowest price at which each agent is willing to sell (henceforth called "sell price") and the highest price at which each agent is willing to buy (henceforth called "buy price"), which can be formulated using the following model:

$$\min \pm p \tag{3.17}$$

$$s.t. \qquad \sum_{i=1}^{3} \frac{1}{(1+\delta_r)^t} CF_{i,n}^t \cdot y_{i,n}^t + \frac{1}{(1+\delta_r)^t} CE_n^t \cdot R_n^t + \sum_{i=1}^{3} \frac{1}{(1+\delta_r)^t} COM_i \cdot x_{i,n}^t - \frac{1}{(1+\delta_r)^t} p^t Q_n^t \leq Cost_{NT} \tag{3.18}$$

In this section, we present the process of solving agents' technology adoption optimization problems considering the allowance trade-off. In each decision interval, agents negotiate the tradable volume of permits at each possible carbon price and adjust their adoption strategies accordingly. Due to the heterogeneity in the production scale and the initial capacities of the technologies, the costs of abatement factors will be different, leading to the heterogeneous acceptance of the carbon price. Some agents tend to sell licenses because their abatement fees are low enough, and somagents tend to buy allowances because their abatement fees are high. However, we do not know in advance which agent will be the seller and the buyer. Therefore, agents' WTP is first calculated with the model to determine the price intervals of agents acting as buyers and sellers. After obtaining the purchase price and selling price of each agent, the feasible time interval for carbon price changes is determined based on the fact that there is at least one seller and one buyer. The reasonable price of carbon is in the distance between the minimum selling price and the maximum buying price [9, 11].

In the feasible price interval, each agent calculates its supply or demand and makes the first bid (e.g., with a combination of price, volume, and direction), and a free auctioneer collects all bids. slow and announces when a transaction occurs. Otherwise, agents adjust their allowance demand or supply and make a second offer. Previous auction information is public to all agents. Trading occurs when a market-clearing price is established to balance supply and demand. The equilibrium price is reached when the total demand for all factors equals the total quantity supplied. Different technologies have different emission coefficients. In our simulation, the diffusion coefficients of T1, T2, and T3 are 0.8, 0.6, and 0.1, respectively. Due to the heterogeneity in the initial technological capacities, the intensity of the initial diffusion of factors is different. Here, emissions in tension represent carbon emissions for the production of one unit of good. Based on the initial distribution intensity of the factors, we measure the intensity inequality of each system using the Gini coefficient. For system k, the Gini coefficient is calculated as

$$G_k = \frac{\sum_{i=1}^{n_k} \sum_{j=1}^{n_k} |S_i - S_j|}{2n_k \sum_{i=1}^{n} S_i} \tag{3.19}$$

In this section, we compare the cases with and without the ETS in terms of technology adoption, total cost, cumulative carbon emissions, carbon price, and total trading volume. The relationship between the emissions trading system and the limits.

In this study, we consider the second approach and investigate the impact of constrained linkages on technology adoption and carbon reduction. In the following simulations, we consider two types of restrictions: exchange rate restrictions and quantitative restrictions. The exchange rate limit means determining the ratio of replacing a unit's license in a foreign system with a subsidy in the domestic system. For example, an exchange rate constraint of 1/2 indicates that the value of a two-unit quota in system A is equal to the value of a one-unit quota in system B. Therefore, if system A imports a subsidy from system B, it is required. Import only half the required volume and if system B imports allowance from system A, it must import double the volume. Quantitative limit means that the maximum volume that any system can obtain through inter-system trades in any period is limited. For example, a quantitative limit of 1/2 means that the maximum allowed volume that agents in system A (or system B) can import is 50 units if system B (or system A) can supply 100 units.

3.1 The relationship between greenhouse gas emission trading system and exchange rate restrictions

In this section, we examine the effect of linking the greenhouse gas emission trading system with different exchange rate restrictions on T3 adoption and carbon reduction. The simulation will be done with the exchange rate limit of 1/5, 1/1 and 1/5. Here, Er = 1/5 means a strict exchange rate restriction to system A and a free exchange rate restriction to system B, and Er = 1/1 means the allowance values are equal in both systems, indicating unrestricted linkage. and we use it as a baseline to compare the impact of different exchange rate restrictions. Imposing a tight exchange rate constraint on system A is likely to promote the adoption of T3, and imposing a loose constraint on system A is likely to discourage adoption of T3. Furthermore, the total system-wide acceptance of T3 after a severe exchange rate restriction is imposed on system A may be even more unrelated. Therefore, when linking the ETS with exchange rate caps, in terms of promoting the adoption of T3, it is better to treat the permits in system A as more valuable and impose a strong exchange rate cap on it. Applying exchange rate restrictions often increases the total cost of one system and decreases the cost of another system, or increases the total cost of both systems simultaneously. Only in a few cases with the pair of Gini coefficients as (0.01, 0.02) and the exchange rate constraint as 1/5, the constrained linkage leads to lower system costs than the unrestricted linkage. Applying a strong exchange rate constraint to system A leads to less car gasoline emissions than unlimited connectivity, and imposing a weak exchange rate constraint to system A is likely to result in more carbon emissions, except for the case with the Gini coefficient (0.03, 0.04). In this case, a free exchange rate restriction to system A also results in lower carbon emissions than unrestricted coupling. Therefore, compared to unlimited connectivity, limited connectivity often fails to achieve a reduction in total carbon emissions with lower system costs. However, there are exceptions, for example, in cases where the pair of Gini coefficients is (0.01,0.02) and the exchange rate limit is 1/5, limiting links to total carbon emissions with lower costs for both systems. They give very favorable results. Compared to the former rate-of-change reduction constraints, more stringent constraints lead to such favorable results. When imposing severe exchange rate constraints on system A, technical laggards tend to adopt T3 much earlier, which lowers their depreciation costs and thus may benefit them in later periods. When imposing weak exchange rate constraints on system A, technical laggards tend to import more permits to meet the carbon abatement target instead of adopting T3, which keeps their abatement costs high and increases the adoption cost and import cost. Applying a strong exchange rate restriction to system A will lead to an increase in the initial price of carbon, and applying a weak exchange rate restriction to system A will lead to an increase in the price. Reducing the initial price of carbon Unsurprisingly, the imposition of exchange rate restrictions is likely to shrink the carbon market. System A is likely to be a net inflow system of grants, and money is likely to flow from System A to System B. This indicates that in the coupled carbon market, system A is more likely to be an importer and system B is more likely to benefit from inter-system trade. This is because agents' market share in system B is not as balanced as that of system A, and technical leaders are more likely to emerge in system B due to technological learning that can benefit from early adoption. In general, the imposition of exchange rate restrictions on the connection between the emissions trading system can reduce the volume of inter-system transactions and monetary flows. Imposing a severe exchange rate constraint on system A is more likely to result in less than minimum utilization than unrestricted connectivity, and this explains why carbon emissions with a severe exchange rate constraint. to system A is less than that in the unlimited link. Furthermore, although imposing a weak exchange rate constraint on system A may also result in less quota usage than unlimited connectivity, due to the multiplicative increase in carbon emissions resulting from the use of quotas from system B in system A, the total Carbon emissions are not reduced throughout the system. This is why imposing an open exchange rate constraint on system A may result in less allowance use, but still result in more carbon emissions than unrestricted coupling. Since the exchange rate constraint is removed for system A, agents in system A are required to import fewer permits to compensate for the same emission, thus reducing T3 acceptance. However, for system B, the utilization rate is not 100% and the excess allowance can be used without causing further T3 acceptance. Therefore, T3 acceptance is not as sensitive to changes in exchange rate restrictions as system A. This is why imposing a severe exchange rate constraint on system A is likely to increase T3 adoption and lower exchange rates. System A restriction is likely to reduce T3 uptake. A strong exchange rate constraint for system A implies that agents in system A must enter more permits to compensate for the same emission. Therefore, by adopting more T3, agents will reduce the import subsidy demand.

In the case of system B, as long as the cost reduction from accepting T3 is less than the cost increase from exporting the lower allowance, its total cost will decrease. Otherwise, it increases. That is why it is difficult to predict the cost change of any system due to the application of exchange rate restrictions. In summary, compared to unrestricted linkage, imposing exchange rate restrictions often fails to reduce total carbon emissions and promote T3 adoption with lower system costs. Limited links reduce the volume of inter-system transactions and thus the flow of money between systems, which can somehow reduce the difficulty of integrating a link. The most important findings of our simulations with different exchange rate restrictions are as follows. When imposing exchange rate constraints, in terms of promoting the adoption of low-emission and carbon-reducing technologies, it is better to consider the contributions in the system with more balanced factor market shares (i.e., system A in the simulations) as more valuable. Such mechanisms encourage companies to invest more in adopting low-emission technologies.

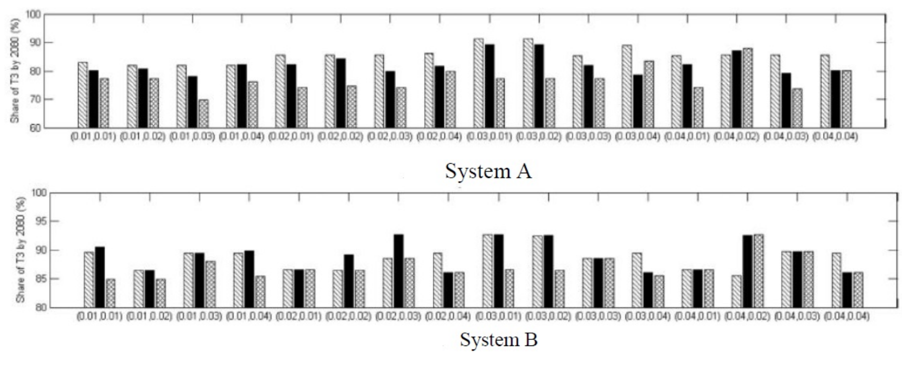

Figure 4: system A and B simulations

3.2 Linking the emissions trading system with quantitative limits

In this section, we examine the effect of coupling the GHG emissions trading system with slightly different constraints on T3 adoption and carbon emissions. For simplicity, we only consider cases where both systems have the same quantity limit, meaning that the quantity limits for the importer and exporter are equal. For example, if the maximum transaction volume that system A can import (or export) from system B is limited to 1/3, the maximum transaction volume that system B can export (or import) to system A is is also limited. Only one discount volume of quotas can be traded between two parties. The two systems show no quantitative restrictions on intersystem trade, indicating unrestricted coupling, and we use this as a baseline to compare the effect of different quantitative restrictions. Imposing quantitative restrictions often leads to T3 uptake, and a tight quantitative restriction is more likely to result in greater T3 uptake. It can be concluded that applying a quantitative limit reduces the tradable volume of allowances in the carbon market and most likely helps the adoption of T3 in system A, which to some extent reduces the permits required for production in system A. (because T3 produces less carbon emissions than the other two technologies). However, the toll demand decreases with the adoption of T3, which means that system B only needs to adopt less T3 to satisfy the allowance demand. Therefore, the costs required for production in system B increase. As long as the increase in allowance use in system B exceeds the decrease in allowance use in system A, the total utilization rate will increase. This is why applying a quantitative limit often leads to lower carbon emissions than unlimited connectivity, while in some exceptional cases it may lead to more carbon emissions.

Linking the emissions trading system can be a cost-effective way for the whole system to meet the carbon reduction commitment and create a carbon market, however, it may limit the diffusion of low-emission technologies and lead to higher total carbon emissions. because the allowances allocated to each emissions trading system will be used more. This means that the permits for any emissions trading system must be redesigned (mainly reduced) to ensure that total emissions do not exceed pre-connection.

The government should be aware that linking the emissions trading system is unlikely to lead to carbon reduction with lower system costs. In some cases, it can reduce total carbon emissions at the cost of increasing the cost of at least one emissions trading system. In such cases, the government could consider subsidizing a more burdensome emissions trading system to make the bond more sustainable. Again, this is much easier if the emissions trading system to be linked is under the same authority. Limited links can reduce the volume of inter-system transactions and money flow between systems, which can somehow reduce the initial problems of a link. When applying exchange rate restrictions, in terms of promoting the adoption of low-emission technologies and carbon reduction, it is better to apply more balanced market shares of valued agents and strict exchange rate restrictions. This is because such mechanisms encourage companies to invest more in adopting low-emission technologies.

4 Conclusion

In this research, we analyzed and simulated the effect of technology and business adoption strategies on the release of greenhouse gas emissions. Using different modeling methods, we modeled the factors and their interactions. Then, using real data and company information, we set the model to real parameters and conditions. Applying different technology and business adoption strategies in the model, we investigated their impact on the release of greenhouse gas emissions. This research helps companies and organizations to choose more appropriate strategies to reduce environmental pollution and reduce greenhouse gas emissions. These analyzes also help relevant organizations and institutions in making policy decisions and environmental measures. Using this research, it is possible to identify different patterns and trends in the performance of companies and the impact of their strategies on the release of greenhouse gas emissions. This information helps the industry, policy makers and environmental research to implement the necessary improvements to preserve the environment and reduce its negative impacts. As a result, this valuable research is used as a research and decision-making tool in the field of environmental preservation and reduction of greenhouse gas emissions and can help organizations and communities to seek appropriate solutions for environmental issues. Although the simulations are very light, they can still provide insight into how linkages and constraints on linkages affect the adoption of low-emission and carbon-reduction technologies.

What is the basic factor modeling in order to release greenhouse gas emissions by considering the heterogeneity of companies and interactions between technology adoption strategies and business strategies? Factor-based modeling for GHG emissions liberalization by taking into account the heterogeneity of firms and the interactions between technology adoption strategies and business strategies can be done as follows: Identifying and measuring influencing factors: In this step, the factors that affect GHG emissions liberalization are identified and measured. These factors may include technologies, policies, companies' capabilities and resources, organizational culture, and other factors related to the company's field of activity. Technologies: Technologies used in various industries can have a significant impact on the release of greenhouse gases. For example, the use of cleaner and energy-efficient technologies in manufacturing industries can lead to a reduction in greenhouse gas emissions. Policies: Government policies and related organizations are important players in controlling and managing greenhouse gas emissions. Policies can include setting environmental standards, encouraging the use of renewable resources, and other similar measures. Capabilities and resources of companies: Capabilities and resources of companies in using clean technologies and reducing greenhouse gas emissions are also very important. For example, companies with access to advanced equipment and strong financial resources can implement cleaner and more sustainable strategies. Organizational culture: The organizational culture of the company plays an important role in determining the strategies for adopting technology and reducing greenhouse gas emissions. An organizational culture that values sustainability and the environment and supports environmental aspects in decision-making can lead to better company performance in terms of reducing air pollution and greenhouse gases. Other factors: Other factors such as laws and regulations, customer behavior and social influences can also affect the release of greenhouse gas emissions.

Definition of agents: In this step, companies are introduced as agents in modeling. Each company is considered as an agent that has its own technology adoption strategies and business strategies. In agent modeling, companies are considered as important agents. Each company acts as a strategic agent in this modeling. Each company has its own technology adoption strategies and business strategies that have a great impact on the release of greenhouse gas emissions. Technology adoption strategies: Any company can switch to cleaner and more efficient technologies in order to reduce air pollution and release greenhouse gases. Companies can invest in research and development of new and innovative technologies. Also, training employees in the field of optimal use of green and clean technologies can have a positive effect on reducing air pollution. Business strategies: Business strategies of companies can also have an impact on reducing the release of greenhouse gases. Some companies may be inclined to use green technologies due to customer pressure, the need to increase customer density, or to compete with their competitors. Also, marketing green and environmental products as a differentiating factor can help attract new customers and increase market share. Other factors such as laws and regulations, public opinion, and customer sentiments can also influence companies' business and technology adoption strategies. For example, government laws and regulations can impose requirements on companies to reduce air pollution and use green technologies. Therefore, in agent modeling, companies' agents are considered as strategic agents for reducing greenhouse gas emissions, and their technology adoption and business strategies affect this emission.

Defining agent behavior: Agent behaviors are modeled based on their technology adoption strategies and business strategies. These behaviors can include the level of investment in green technologies, the use of renewable resources, reducing energy consumption, and the like. Agents' behavior in agent modeling is formed based on their technology adoption strategies and business strategies. In the following, I will explain how these behaviors can be modeled in order to reduce the release of greenhouse gases. Level of investment in green technologies: Companies can invest in research and development of cleaner and more efficient technologies. They can adopt proactive strategies including investing in solar, wind, hydrogen, battery, and clean energy production systems. Also, they can commercialize existing green technologies and market them. Use of renewable resources: Companies can focus on the use of renewable energy sources such as the sun, wind, water, biogas, etc. They can use solar and wind energy production systems in their processes and use energy reduction technologies and smart building management systems. Reducing energy consumption: Companies can adopt strategies to reduce energy consumption in their production processes and operations. This includes optimizing processes, using low-energy technologies, improving system performance, and using optimal resource consumption. Supportive policies: Firms may spontaneously choose business strategies and technology adoption because of the financial and environmental benefits associated with reducing greenhouse gas emissions. Some supporting and encouraging policies such as financial facilities, tax reduction, granting green business certificates and sustainable consumption patterns can help companies adopt green strategies. By combining these behaviors, companies can plan to reduce greenhouse gas emissions and help preserve the environment and create sustainable development.

Modeling interactions: In this step, interactions between agents are modeled. These interactions can include cooperation, competition, information exchange and other relationships between companies. Interaction modeling can help to better understand the correlation effects and influence of one company on other companies. Modeling the interactions of agents is very important in the studies of relationships between companies and their influence on each other. These interactions can include cooperation, competition and information exchange and can be of great importance to better understand the effects of solidarity and the influence of one company on other companies. In the case of cooperation, the interaction of two or more companies in order to provide higher quality products or reduce costs can lead to improved company performance and greater productivity. For example, two companies can collaborate on research and development to produce cleaner and more efficient technologies that can lead to better productivity and reduced energy consumption. In the case of competition, the interactions in which firms compete can greatly affect a firm's profitability and market power. By modeling the competition, companies can find the best solutions to compete with other companies and, as a result, achieve better growth and greater productivity. In addition, interactions between firms can include information exchange that can help improve firms' strategic decisions. For example, interacting to introduce new technologies to each other can help discover new opportunities for growth. Considering these interactions, modeling the interactions of agents helps companies to choose the best solutions and strategies to improve their performance and to take appropriate actions for sustainable growth and environmental preservation, by cooperating and interacting with other companies.

Analysis and simulation: After modeling the factors and interactions, using analysis and simulation methods, the effect of technology and business adoption strategies on the release of greenhouse gas emissions is investigated. These analyzes can help to recognize the heterogeneity and different patterns in the performance of companies. Analyzing and simulating the impact of technology adoption and business strategies on GHG emissions will help us gain a better understanding of how different strategies in technology and business can have an impact on GHG emissions. In this analysis, we first model the factors and their interactions using different methods such as neural networks, mathematical models, and evolutionary algorithms. Then, using real data and information about companies, we fit our model to real-world parameters and conditions. By applying different technology and business adoption strategies to the model, we can examine their impact on GHG emissions liberalization. For example, we can consider a situation where a company invests in cleaner and more efficient technologies and the result is less release of greenhouse gases. Also, we can consider the impact of various business strategies such as increasing sales market, reducing costs and managing supply chain. By performing this analysis and simulation, we can identify different patterns and trends in the performance of companies and the impact of their strategies on the release of greenhouse gas emissions. Also, we can monitor different conditions and examine the effects of different strategies on greenhouse gas emissions over time. These analyzes help companies as decision makers to choose more appropriate strategies to reduce environmental pollution and reduce greenhouse gas emissions. Also, these analyzes can help relevant organizations and institutions in making policy decisions and environmental measures.

What is the effect of business strategy and technology adoption strategies on the release of greenhouse gas emissions? In general, the impact of business strategy and technology adoption strategies on the release of greenhouse gas emissions depends on the following factors: Energy consumption: Business strategies and technology adoption that lead to less energy consumption and improved energy efficiency lead to a direct reduction in the release of greenhouse gases. For example, the use of more efficient cooling systems and technologies in industries and equipment will reduce energy consumption, resulting in less greenhouse gas emissions. Choice of energy sources: Technology adoption strategies also have a great impact on the choice of energy sources. Using renewable energy sources such as solar, wind, hydropower, etc. instead of fossil fuels reduces the release of greenhouse gases. Business strategies that focus on choosing clean energy sources allow companies to reduce the level of greenhouse gas emissions while presenting an appropriate image of themselves as a sustainable and responsible company. Supply chain management: Business strategies and technology adoption can play an important role in improving supply chain management. By reducing waste, optimizing processes and using advanced technologies in transportation and storage, the amount of greenhouse gas emissions associated with the supply chain will be reduced. Changing consumer behavior: Business strategies and technology adoption can play an important role in changing consumer behavior. For example, offering sustainable, environmental, and low-GHG products can encourage customers to prefer purchasing these types of products. This action can directly lead to the reduction of greenhouse gas emissions by companies.

The impact of business strategy and technology adoption strategies on the release of greenhouse gas emissions depends on several factors. In the following, I will mention some of these influences: Business strategies: Companies' business strategies can have a large impact on the release of greenhouse gas emissions. For example, companies that adopt a cleaner production strategy and use clean energy sources and less polluting products are likely to reduce the level of greenhouse gas emissions. Technology adoption strategies: Technology adoption strategies can also have a significant impact on greenhouse gas emissions. For example, the use of new and clean technologies in energy production and transmission processes directly reduces greenhouse gas emissions. Government policies: Government policies focusing on reducing greenhouse gas emissions and encouraging the use of clean energy sources and new technologies can make a significant difference in the release of greenhouse gases by companies. Government policies in the form of tax exemptions, financial support and incentives for the use of clean energy sources can encourage companies to adopt strategies that lead to the reduction of greenhouse gas emissions. In summary, business strategy and technology adoption strategies can help reduce greenhouse gas emissions by implementing process changes, using clean energy sources, and improving supply chain performance. It is also important to strengthen government support and change consumer behavior in order to reduce the harmful effects of climate change.

What is the role of each of the technological capabilities in the influence of business strategy and technology adoption strategies on the release of greenhouse gas emissions? Each of the technological capabilities can directly and indirectly play a role in reducing the release of greenhouse gases and influencing the business strategy and technology adoption strategies of companies. Innovation: By using innovation, companies can directly reduce the release of greenhouse gases related to their activities. Also, finding new and innovative solutions in the field of reducing greenhouse gas emissions helps companies compete in the global market and choose responsible strategies. Automation and artificial intelligence: improving efficiency and reducing energy consumption using automation and artificial intelligence leads to a reduction in the release of greenhouse gases. Also, the use of these capabilities is also effective in the business strategy of companies, because it leads to improving efficiency and reducing costs, improving the company's competitiveness and attracting new customers. Information and communication technology: By improving the management and control of processes, internal and inter-company communication and reducing activities that lead to the release of greenhouse gases, the use of information and communication technology plays an important role in the business strategy and technology adoption strategies of companies. This capability is effective in attracting new customers and improving the relationship with existing customers. Research and development: looking for new and advanced solutions in the field of reducing greenhouse gas emissions, leads companies to develop green and sustainable technologies, which indirectly affects the business strategy and technology adoption strategies of companies. Green technology: The use of green and sustainable technologies can help companies adhere to their responsibility strategies, while also being effective in their business strategy, as they help attract new customers and compete with other companies that use these technologies. have put in their production and service process, they are effective.

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