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Efficiency evaluation of international carbon market link limit mechanism in the context of carbon neutrality

Hanying Jiang[1,5], Jiachen Wang[1,5], Sha Yu[2,3], Xinzhu Zheng[4] and Can Wang[1*]

1 State Key Joint Laboratory of Environment Simulation and Pollution Control, School of Environment, Tsinghua University, Beijing 100084, China

2 Joint Global Change Research Institute, Pacific Northwest National Laboratory, MD 20740, USA

3 Center for Global Sustainability, University of Maryland, MD 20742, USA

4 School of Economics and Management, China University of Petroleum, Beijing 102249, China

5 These authors contributed equally to this work and should be considered co-first authors.

(*Corresponding Author: canwang@tsinghua.edu.cn)

ABSTRACT

Article 6 of the Paris Agreement enables Parties to achieve their Nationally Determined Contributions (NDCs) through direct cooperation or Internationally Transferred Mitigation Outcomes (ITMOs). Current researches on Article 6 are mostly based on the assumption of unlimited global carbon market link, which may lead to large price volatility and cause concern of policy makers. Here, we designed carbon market link scenarios with different degrees of trading volume limits, and simulated the global and regional carbon markets under different scenarios from 2025 to 2060 using the Global Change Assessment Model (GCAM). The findings suggest that as the link limit tightens, both the price volatility of global carbon market and the cumulative mitigation costs saved by carbon market links decrease. The price volatility under the unlimited global carbon market scenario is about 30% higher than that with link limits implemented. At the national level, a total of 15 regions are constrained in different link limit scenarios, among which China, the United States, EU and India are the most sensitive regions to link limits. Based on the scenario results, we discuss the design and impact of different international carbon market link limit mechanisms, such as absolute link limits and relative link limits.

Keywords: Paris agreement, article 6, emissions trading system, limited link, cost-effectiveness, carbon price volatility

ABBREVIATIONS

NDC	Nationally Determined Contribution
ITMO	Internationally Transferred Mitigation Outcome
GCAM	Global Change Assessment Model
ETS	Emissions trading system

1. INTRODUCTION

Climate change is considered to be the most serious threat facing humanity today, and with the continuation of fossil fuel burning and greenhouse gas emissions at current trends, global average temperatures could rise to catastrophic levels and lead to disastrous consequences. The Paris Agreement established the Nationally Determined Contributions (NDCs) mechanism for bottom-up international cooperative action on climate change, and established a voluntary cooperative emission reduction mechanism based on the market mechanism[1].

Emissions trading system (ETS) is a market-based policy instrument for reducing greenhouse gas emissions, and are playing an increasingly important role in global environmental governance as a crucial way to implement carbon pricing. Cooperative approaches on a voluntary basis are proposed in Article 6 of the Paris Agreement[1], where cooperative market mechanisms allow parties to reduce the total cost of emission reductions, and facilitate the transfer of finance and technology to developing countries. Article 6 of the Paris Agreement enables Parties to achieve their NDCs

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through direct cooperation or Internationally Transferred Mitigation Outcomes (ITMOs), contributing to their more ambitious targets. As carbon neutrality is becoming a mainstream global climate change policy goal, international cooperation to address climate change is facing an unprecedented demand.

Among the studies on Article 6, most current studies are from the standpoint of developed countries, focusing on the potential reduction of mitigation cost induced by carbon market links and the opportunities to increase the emission reduction ambitions, and analyze carbon market link based on the assumption of unlimited global carbon market link[2]. However, unlimited link can lead to price convergence among interlinked systems, leaving jurisdictions with higher allowance prices facing falling prices, and jurisdictions with lower allowance prices facing rising prices. Few studies have investigated the price volatility brought by the carbon market link. As for the alternatives to the ideal unlimited global carbon market, some studies suggest that the carbon market link limit or sectoral limit mechanism should be applied, and others believe that countries committed to reducing emissions can establish appropriate global climate governance frameworks only by establishing climate clubs or adopting carbon border adjustment mechanisms[3-5].

The innovation of this study is that we extend the research framework of the bilateral carbon market link limits to multilateral carbon market link limits, and quantitatively explore the impact of carbon market ink on national/regional carbon price volatility and how price volatility can be hedged with link limits. The results of this study can provide insights into the regional volatility implications of international mitigation cooperation. To better inform policies under carbon neutrality targets, the analysis extends to 2060.

In this study, we set up different carbon market link scenarios and used the GCAM model to simulate regional and global carbon markets under different scenarios from 2025 to 2060. We attempt to answer the following three research questions: (1) To what extent do international carbon market link limits affect carbon market volatility and carbon market trading? (2) How do relative and absolute limits work differently for limited countries and affect carbon market link? (3) Which countries are more sensitive to carbon market link limits, and how do link limits affect typical countries?

2. METHODOLOGY

2.1 Scenario settings

We used the release of GCAM 5.4[6], a model widely used in global and national mitigation policy analysis, to simulate different international carbon market link scenarios. We followed the near-term to net-zero approach described in Ou et al. to configure national emission pathways[7], and evaluated countries independently, cooperatively and limited cooperatively to achieve climate goals using the scenario approach. Population and GDP assumptions follow the “middle of the road” SSP2, which is widely used in integrated modeling studies[8].

In order to investigate the impact of international carbon market link on global climate action, this study designed different international carbon market link scenarios, which is the SINGLE scenario, the GLOBAL scenario and the LIMIT scenario. Among which, the LIMIT scenario is divided into different types and levels of link limits to further explore the impact of international carbon market link limits and the related mechanism design. The assumptions of each international carbon market link scenario are shown in Table 1, in each scenario, the same level of national emission reduction ambition is maintained for each country.

Table 1 Scenario Assumptions

Scenario Name	Scenario Description
SINGLE Scenario	Each country forms a national carbon market independently, with no link among national carbon markets, and each country independently meets its own carbon reduction targets.
GLOBAL Scenario	There is a global carbon market in which all countries participate, with unlimited international carbon market link and full cooperation among countries to meet carbon reduction targets.
LIMIT Scenario Group	There is a global carbon market in which all countries participate together, and there are limits to the international carbon market link. Countries are not allowed to trade national carbon allowances exceeding the limits, and countries will cooperate to accomplish their carbon reduction targets under the limited link. This scenario group consists of three parts: reference LIMIT scenario, RELATIVE LIMIT scenario group and ABSOLUTE LIMIT scenario group.

2.2 Link limit settings

In terms of applying the link limit for international carbon market, this study takes countries as the limit target, and limits the trading volume of each country in the international carbon market. The carbon market trading volume limits for countries can be classified into two types, namely absolute limits and relative limits, corresponding to the different link limit mechanisms.

In this study, the absolute limit refers to the absolute value of countries' trading volume, and the relative trading limit is relative to the emission reduction volume of each country, which means that the country should bear its emission reduction obligation to a certain extent and should not overburden other countries. In the reference LIMIT scenario, the upper limit of each country's trading volume in the carbon market is:

$$lim_{it} = MAX\{500MT\ CO_2eq, 20\%R_{it}\} \qquad (2.1)$$

Where lim_{it} denotes the limit (in absolute terms) on the amount of carbon allowances traded in the international carbon market for country *i* at year *t*, and R_{it} denotes the emission reduction ambition of country *i* at year *t*, where country i denotes any of the regional carbon market counterparties in the global carbon market in GCAM. To derive the emission reduction ambition of each country, first, we simulated the no climate policy scenario and derive the counterfactual emission pathways for countries. Second, these counterfactual emission pathways minus the NDC- and LTS-aligned emission pathways (described as above) to derive the emission reduction ambition for each country. Note that the choice of the reference LIMIT (absolute limit for 500MT, and relative limit for 20%) is arbitrary. To eliminate the influence of this choice, we additionally run two groups of LIMIT scenarios as sensitivity analysis, namely RELATIVE LIMIT scenario group and ABSOLUTE LIMIT scenario group.

RELATIVE LIMIT scenarios and ABSOLUTE LIMIT scenario are further used to investigate the differences between the two link limit mechanisms. In the RELATIVE LIMIT scenario group, the relative limits are set at 5%, 10%, 20%, 30% and 50% respectively, with absolute limit fixed at 500 MT CO2eq. In the ABSOLUTE LIMIT scenario group, the absolute limits are set at 200MT CO2eq, 300MT CO2eq, 500MT CO2eq, 700MT CO2eq and 900MT CO2eq respectively, with relative limit fixed at 20%.

Note that the version of GCAM used in this study lacks the capability to set international carbon market trading volume limits explicitly. The post-processing approach and trial-and-error method are adopted. That is, the regions exceeding the trading volume limits in the GLOBAL scenario are selected as initial guesses. These regions are extracted from the international carbon market one by one, and then configured with revised emission pathways equal to the original NDC- and LTS-aligned emission pathways plus/minus the trading volume cap (depending on their buyer/seller position in the international carbon market). The remaining regions trade freely, and regions exceeding the trading volume limits continue to be extracted. Through this iterative process, LIMIT scenario groups are simulated.

2.3 Cost-effectiveness metrics and volatility metrics

This study adopts "deadweight loss" approach to measure the welfare losses associated with abatement efforts, which takes advantage of GCAM's detailed technological characterization [43]. This study calculates the cost of abatement at each time step, and costs between time steps by linear interpolation. Over time, the total cumulative cost can be summed and the abatement cost for an individual year is calculated as:

$$Mitigation\ cost_{it} = \frac{P_{it} * (E_{ref\_it} - E_{incr\_NDC\_it})}{2} \qquad (2.2)$$

Where $Mitigation\ cost_{it}$ is the abatement cost of country *i* in a single year at year *t*, P_{it} is the carbon price for country *i* at year *t* under the SINGLE, GLOBAL and LIMIT scenarios, E_{ref_it} is the counterfactual emissions of country *i* at year *t* under the no climate policy scenario, and $E_{incr\_NDC\_it}$ is the emissions of country *i* at year *t* under the SINGLE, GLOBAL and LIMIT scenarios.

This study calculates the global and regional carbon market price volatility indicator by weighting the carbon price volatility of each region with carbon emissions:

$$\text{Volatility indicator}_j = \frac{\sum_{t=1}^{n} \frac{\sum_i \left|P_{it} - P'_{itj}\right| \times \frac{\left|E_{it} - E'_{itj}\right|}{2}}{\sum_i \frac{\left|E_{it} - E'_{itj}\right|}{2}}}{n} \qquad (2.3)$$

Where $\text{Volatility indicator}_j$ denotes the carbon market price volatility in scenario *j*, P_{it} denotes the carbon price of region *i* in the SINGLE scenario at time point *t*, and P'_{itj} denotes the carbon price of region *i* in scenario *j* (GLOBAL or LIMIT) at time point *t*; E_{it} denotes the carbon emissions of region *i* in the SINGLE scenario at time point *t*, and E'_{itj} denotes the carbon emissions of region *i* in scenario *j* (GLOBAL or LIMIT) at time point *t*; *n* denotes the number of time points considered, since the pathway considered is from 2025 to 2060, and the GCAM model takes 5 years as the time step, there are 8 time points in total.

3. RESULTS

3.1 Impact of link limits on the global carbon market

Figure 1 illustrates that the price volatility of the global carbon market in the reference LIMIT scenario is milder than that in the GLOBAL scenario. Where X represents the link limit (in absolute terms) in the series of ABSOLUTE LIMIT scenarios, the unit is million tons CO2eq. K represents the link limit (in relative terms) in the series of RELATIVE LIMIT scenarios. The price volatility index of the global carbon market is 79.83 in the GLOBAL scenario and 61.60 in the reference LIMIT scenario.

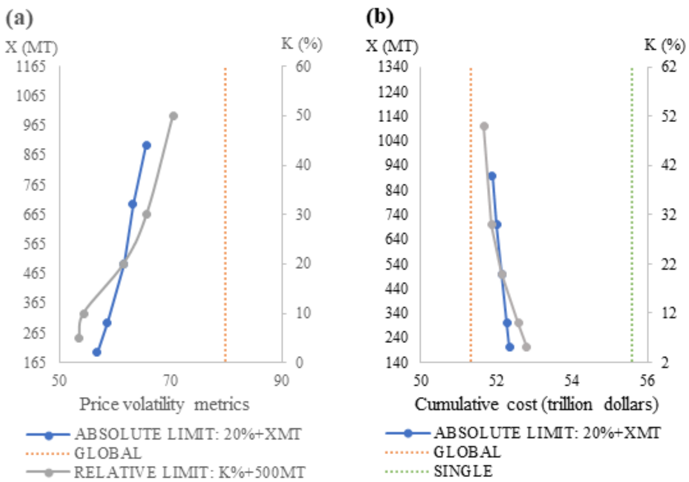

Fig. 1. Price volatility and cumulative mitigation cost

With the link limit tightening, both the price volatility of global carbon market and the cumulative mitigation costs saved by carbon market link decrease. The 50%&500MT LIMIT scenario presents the highest price volatility index of 70.53, while the 20%&200MT LIMIT scenario presents the lowest price volatility index of 53.54. In the RELATIVE LIMIT scenarios, the volatility index falls from 65.67 to 56.76 as the relative limit tightens, while in the ABSOLUTE LIMIT scenarios, the index falls from 70.52 to 53.54 as the absolute limit tightens.

The GLOBAL scenario maximizes the cost-effectiveness of the international carbon market, with the global cumulative mitigation cost from 2025 to 2060 being $51.31 trillion, which saves $4.26 trillion compared to the SINGLE scenario, using the constant price of 1990 US dollars. In the LIMIT scenarios, the mitigation costs saved by carbon market link are less than that in the GLOBAL scenario, and the saved cost reduces with the tightening of the link limits. The global cumulative mitigation cost varies with the link limit changes in a larger range in the RELATIVE LIMIT scenarios than in the ABSOLUTE LIMIT scenarios.

Figure 2 presents that the trading volume and trading amount of the global carbon market decrease as the link limit tightens. Where The ABSOLUTE LIMIT scenarios are presented with 20% link limit (in relative terms) and different level of link limit (in absolute terms), ranging from 200MT CO2eq to 900 MT CO2eq. The RELATIVE LIMIT scenarios are presented with 500MT CO2eq (in absolute terms) and different level of link limit (in relative terms), ranging from 5% to 50%. Under the unlimited global cooperation scenario, the total trading volume of the international carbon market rises from 3559 MT CO2eq in 2025 to a maximum of 5583 MT CO2eq in 2060. The trading volume of the international carbon market with link limits is lower than that of the GLOBAL scenario.

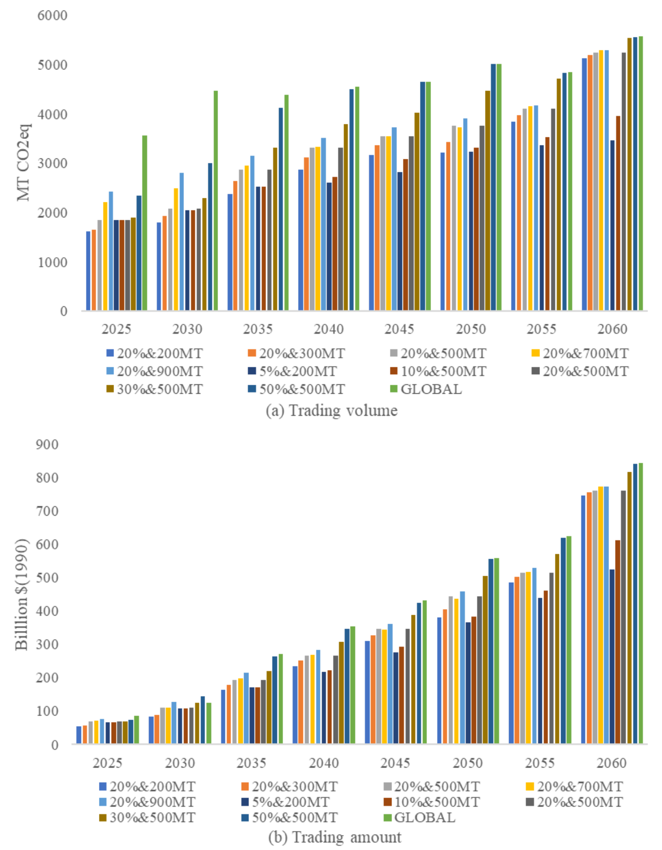

Fig. 2. Trading volume and trading amount

With the continuous rise in carbon price, the total trading amount of the international carbon market under the global cooperation scenario increases rapidly from $86.27 billion in 2025 to a maximum of $843.92 billion in 2060. The trading amount of the international carbon market with link limits shows the similar trend of the trading volume, as the link limit tightens. In the RELATIVE LIMIT scenarios, the trading volume and trading amount of global carbon market presents larger variation than those in the ABSOLUTE LIMIT scenarios.

3.2 Link limits at the national scale

A total of 15 regions are limited in different scenarios with varying degrees of carbon market link limit. Figure 3 presents the scenarios in which these regions are constrained by the link limit and the type of link limit (relative limit or absolute limit) to which these regions are more sensitive. In Figure 3, if the block is yellow, the region is more strictly constrained by the absolute limit in the link limited scenario; if the block is purple, the region is more strictly constrained by the relative limit; if the color of the block is white, the region is not constrained by any link limit. The ABSOLUTE LIMIT scenarios are presented with 20% link limit (in relative terms) and different level of link limit (in absolute terms), ranging from 200MT CO2eq to 900 MT CO2eq. The RELATIVE LIMIT scenarios are presented with 500MT CO2eq (in absolute terms) and different level of link limit (in relative terms), ranging from 5% to 50%.

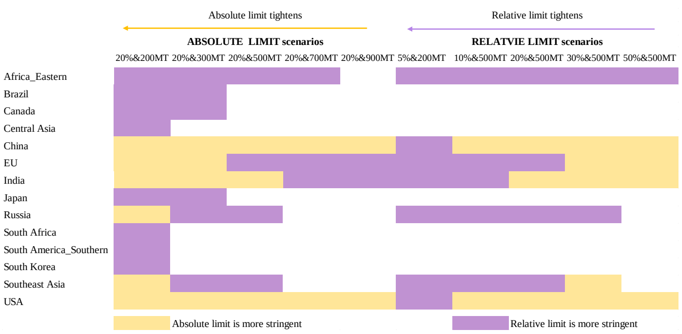

Fig. 3. Sensitivity of constrained regions in LIMIT scenarios

Overall, Africa_ Eastern, Brazil, Canada, Central Asia, EU, Russia and Southeast Asia are more sensitive to the relative limit (with more purple color blocks in Fig. 3), while China, India, and the U.S. are more sensitive to the absolute limit (with more yellow color blocks in Fig. 3). The relative-limit-sensitive regions are characterized by the relatively small absolute trading volume and relatively large ratio of the trading volume to their emission reduction ambition. The absolute-limit-sensitive regions are characterized by the relatively large absolute trading volume and relatively small ratio of the trading volume to their emission reduction ambition.

China, the United States, the European Union, and India are the most sensitive regions to the international carbon market link limits, and are constrained in all the link limit scenarios. Figure 4 presents the regional carbon price volatility of these regions, where X represents the link limit (in absolute terms) in the series of ABSOLUTE LIMIT scenarios, the unit is million tons CO2eq. K represents the link limit (in relative terms) in the series of RELATIVE LIMIT scenarios. It can be found that the regional carbon price volatility decreases as the link limit

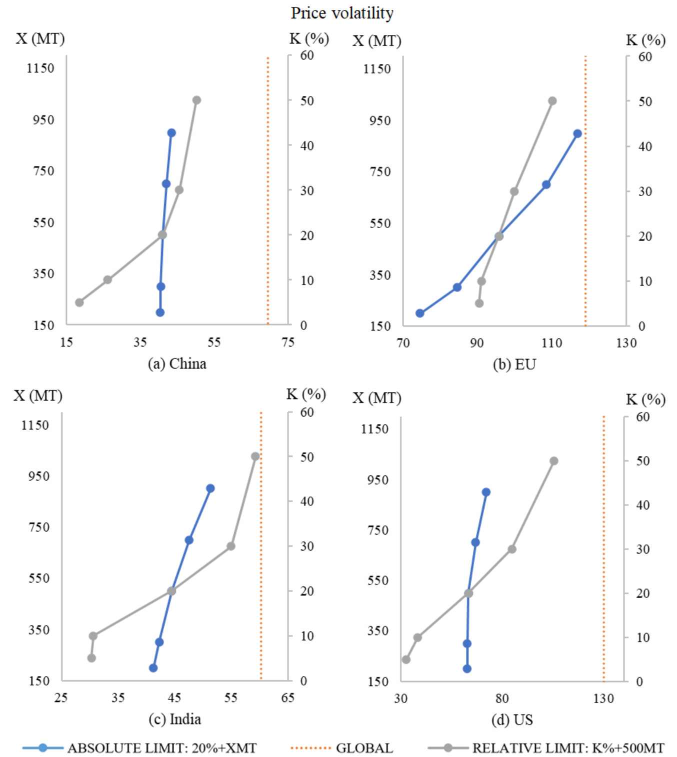

Fig. 4. Price volatility of the regional carbon market

tightens, consistent with the global carbon price volatility. Among the four regions, the U.S. and the EU experience higher price volatility than China and India, due to the higher regional carbon price and the greater price differences between GLOBAL and SINGLE scenarios. Besides, the variation of the price volatility of China, the U.S. and India presents larger range in RELATIVE LIMIT scenarios, while the EU present larger range in ABSOLUTE LIMIT scenarios than in RELATIVE LIMIT scenarios. This heterogeneity needs to be considered in the design of the global carbon market link mechanism.

Figure 5 presents the international carbon market financial flows of the four typical regions under different link limited scenarios. Where the ABSOLUTE LIMIT scenarios are presented with 20% link limit (in relative terms) and different level of link limit (in absolute terms), ranging from 200MT CO2eq to 900 MT CO2eq. The RELATIVE LIMIT scenarios are presented with 500MT CO2eq (in absolute terms) and different level of link limit (in relative terms), ranging from 5% to 50%.

Compared with the unlimited global cooperation scenario, international carbon market link limits will not affect the direction of financial flows among regions, and will not change the regions' identity as buyers or sellers. However, link limits will lead to smaller magnitude of financial flows, and the regional trading volumes and trading amounts decrease as link limits tighten.

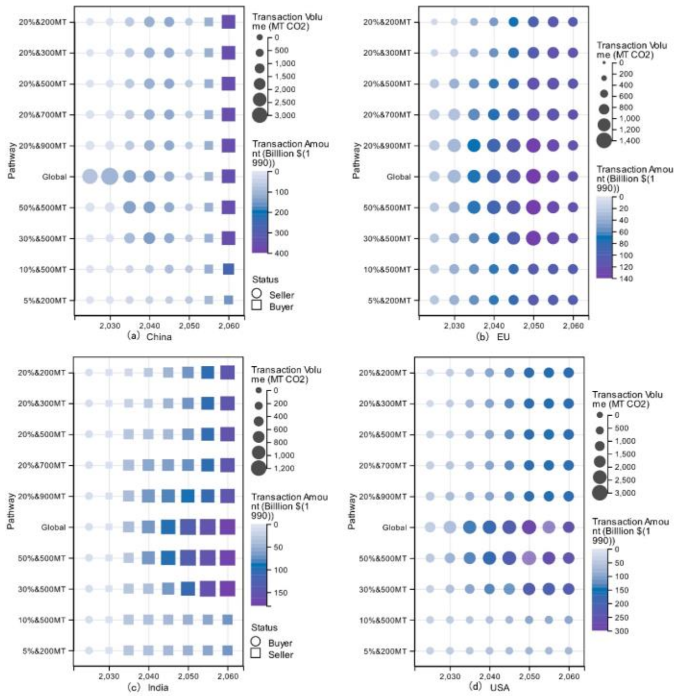

Fig. 5. Regional trading volume and trading amount

4. DISCUSSION & CONCLUSION

This paper validated the cost-effectiveness of the international carbon market link in the context of carbon neutrality, filled the gap of exploring the impact of link limit mechanism on international carbon market transactions, global mitigation costs and regional carbon price volatility. We further explored the differences between the absolute and the relative link limit, and examined the countries' sensitivity to these link limits.

As the link limit tightens, both the price volatility of the global carbon market and the cost-effectiveness of international carbon market links decrease. The ability of the international carbon market link to reduce global mitigation cost is validated in this study under the carbon neutrality targets. However, there is a trade-off when implementing the international carbon market link limit mechanism.

A total of 15 regions are constrained by link limits in this study's scenarios. Among them, China, U.S., EU and India are the most sensitive regions to the international carbon market link limits. Regions with larger trading volumes in the international carbon market are more sensitive to the absolute link limits, while regions with the larger ratio of the trading volume to their emission reduction ambition are more sensitive to the relative link limits. The heterogeneity of the regional carbon market responses to link limits may have significant implications on the equity problem and need further exploration.

Regional trading volume and trading amount in the global carbon market both reduce with more stringent link limits. However, the direction of the financial flows among regions remains unchanged. This is because the link limits do not change the regional position as buyers or sellers in the global carbon market. The buyer or seller position is determined by regional marginal mitigation cost curves and regional emission reduction ambitions. That is, besides link limit settings, regions can improve the financial flows in the global carbon market by low-carbon technology innovation and lowering regional marginal mitigation costs.

The price volatility studied in this paper is only a first-order approximation. Future research can investigate the impact of international carbon market links on the operation of the domestic carbon market with higher temporal resolution. More detailed representation of the domestic carbon market can be nested with the international carbon market based on the Armington hypothesis. In addition, the broader impacts of the international carbon market link on the Sustainable Development Goals needs further consideration.

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