The impact of carbon leakage controlling mechanisms on international trade: A review

Yingqi Zhang*

Beijing Royal School, Beijing, China

*Corresponding author: zhangyingqi@st.brs.edu

Abstract. Proposition of Carbon Border Adjustment Mechanism Since the "Kyoto Protocol" came into effect, developed countries have adopted strict policies to control the emission of greenhouse gases, and the topic of carbon leakage mechanism has attracted the attention of scholars. This article reviews the major academic works published in the past decade on carbon leakage and its control mechanisms. The works are categorized into "carbon leakage", "carbon leakage controlling mechanism" and "impacts on international trades" according to their research focuses. Clear patterns regarding transitions of their research focus and methodologies have emerged during the review process. This article revealed that during the past decade the perspective of relevant research has altered from unilateral (domestic) point of view to the multilateral view, the focus has moved from the developed world (the EU in particular) to the developing world (like China and India), and the research method has incorporated more and more quantitative models to gain insights from multi-dimensional data. Despite that this work is neither exhaustive nor vital for unsettling matters of climate bargaining, the review shed light on what can be borrowed, what can be avoided and what requires more trial-and-error attempts to modify and adapt mature climate mechanisms for developing economies like China.

Keywords: Carbon Leakage, Border Adjustment, International Trade.

1. Introduction

1.1 Research Background

On 15 March 2022, the Council of the EU stroke an agreement (general approach) on the Carbon Border Adjustment Mechanism (CBAM) regulation, which marks a milestone for the European Union's intermediate target of reducing the emission of greenhouse gas by 55% by 2030 (the 'Fit for 55' package) and the ultimate goal of achieving climate neutrality in the EU region by 2050. The CBAM mainly serves the purpose of restraining carbon leakage and foster establishing effective carbon pricing policies in partner economies to fight against the exacerbating climate change. Carbon leakage stems from conflict between the universality of greenhouse effect-the climate change and inconsistent policies employed by different economies with respect to treating the greenhouse emissions. More sustainable and environmental-friendly producing procedures are more likely to incur higher costs, therefore manufacturers constrained by tighter climate policies intend to transfer productions to places with laxer constraints, which would undermine the efficiency of such regional policies since the effect of greenhouse gas emissions is not regional. Carbon leakage is apparently a stumbling block to the mitigation of climate change, and various efforts (controlling mechanisms) have been made to overcome it. One cornerstone of such efforts is the EU Emissions Trading System (EU-ETS) – the first and currently the largest major carbon market all over the world. The ETS sets a Union-wide 'cap' (permission) for the gross volume of greenhouse gas emissions from corporations, while within the cap entities are allowed to trade 'emission allowances' (one allowance permits the holder to emit additional one tone of CO_2 or the equivalent amount of other powerful greenhouse gases, N_2O and perfluorocarbons) with each other. Despite of its ingenuity, the ETS could not be accomplished at one stoke without incurring catastrophic shock to European economies. Thus, four phases (until 2030) with progressive parameters have been set, and we have entered the final phase (2021-2030) of this schedule. The cap on total emissions is set to decrease annually at an accelerated pace (annual linear reduction factor of 2.2% (the factor was 1.74% for pervious phase)). Moreover, the system can effectively alleviate carbon leakage within the European Union though, it cannot prohibit further leakage beyond the Europe continent. Catering to such 'risk', the European Commission officially specified three lists (for three consecutive phases) of sectors and sub-sectors considered to be exposed to "significant risk of carbon leakage", and the listed sectors are eligible for higher shares of free allocation for each installation of the ETS.

EU's endeavor against climate change is a pioneering yet special attempt. Frictions of cross- border trade, traveling, capital flow (including human capital) and information exchange are at almost lowest level, and their similar societal progression stage and cultural background cultivated similarly high-level public acceptance of long-term environmental policies even at the cost of short-term economic gains. However, such tacit understanding among countries is extremely rare in a global context. Textile factories in China cannot bear similar sustainability requirements imposed on designing houses in France mainly because they act as different roles in one coherent supply chain of apparel industry. Therefore, carbon leakage controlling mechanisms in a global context are bound to suffer more complications than regional policies like the EU-ETS.

1.2 Research Significance

As elaborated in the previous session, carbon leakage is one of the major drawbacks of any environmental effort against climate change, and the corresponding controlling mechanisms require meticulous consideration to be evaluated and negotiated. One significant part of such consideration is their impact on international trades. Despite of recent surging geopolitical conflictions, globalization and international specialization have brought many countries out of poverty and are inevitable trends non-trivial than the fight against climate change. On the other hand, carbon tariff imposed on traded goods is one of the most popular controlling mechanisms targeting at carbon leakage (because there has been no global equivalence of the European Commission to establish a world emission trading system yet). Therefore, clarifying the impacts of such controlling mechanism on international trades can help the policy makers better evaluate such policy proposals and help the general public better understand how such policies would influence their daily life. The COVID-19 pandemic and recent Russian special military operation has catalyzed the reformation of a new world order. In the process we can spot that trade sanctions, capital controls can be weaponized and utilized against one country besides military forces, and can even cause more severe and profound damages. Since mitigating the climate change is an indispensable (although in a longer term) responsibility for all human to survive, bargaining the terms before the rules are settled is a more initiative and advantageous stance than passively accepting the rules. From a strategic perspective, our research can help measure the cost of imposing carbon leakage controlling mechanism in a more precise way, and lead to wiser political moves confronting the 'common enemy' - the climate change.

1.3 Paper Organization

In the following Session 2.1, the definition of carbon leakage phenomenon, its measurement and impacts on the climate are elaborated through previous works. In Session 2.2, three major categories of carbon leakage controlling mechanisms are presented and compared: the carbon tax/tariff (Session 2.2.1), carbon trade (Session 2.2.2) and policy spillovers (Session 2.2.3). After introducing the controlling mechanisms, their impacts on the international trades are elaborated in Session 2.3. The major contributions of this work are presented in Session 3.1, and finally the limitations in Session 3.2.

2. Literature Review

2.1 Carbon Leakage

Lin and Sun analyzed the "embodied CO_2 emissions" of China's imports and exports with the methodology of single-regional input-output analysis (IOA). They found that during the year of 2005, 3.36 billion tons of CO_2 emissions had been embodied in the exports compared to 2.33 billion tons of

CO_2 emissions had been avoided by imports (EAI), which implied that under the climate policies and international trade rules back then (in 2005), carbon leakage had occurred in China – more carbon emissions exported (produced) than imported (consumed). The research called for new global climate framework to balance emission responsibilities and advised China to make further reforms regarding energy structure and to bear more responsibility in this global effort. In addition, they also performed sector-based analysis for China as well, and found the machinery and electrical equipment manufacturing industry had the highest levels of emissions embodied within export/import products and net embodied emissions of trade balance among all 15 investigated sectors. Sectors output low value-added products were more likely to be carbon net importers, while manufactory producers and service providers were carbon net exporters [1]. Elliott, Foster has investigated how carbon tax policies would perform when international trade counterparts imposing different tax rates with a quantitative method of CIM-EARTH (a computable general equilibrium (CGE) model). They argued that the international trade could accentuate the free-riding problem of imposing regional carbon taxing policies, and suggested a possible policy response – to tax on carbon intensive imports with a rebate for exports – in which domestic producers would not be at disadvantageous position compared to their competitors with laxer carbon taxations. The validity of their newly introduced CIM-EARTH model was supported by the consistence between simple economic analysis and the qualitative predictions output by the model. More quantitatively, their model predicted that, given the carbon tax level of $29 per ton of CO_2 imposed on producers, the increased CO_2 emissions from developing economies due to carbon leakage would offset over 20% emission reduced by the Annex B Kyoto region. Although Elliott, Foster declared the limitations and further improvements (like evaluating the sensitivity of results to the key parameters used in the model) that can be made to their model and consequent results, the direction of their conclusion cast a shadow on any ambitions regional climate cooperation and highlighted the necessity of controlling carbon leakage [2]. Wang and Yang took China and India as example countries to investigate the imbalance of carbon embodied in South-South trade. The two are the fastest growing economies in terms of both carbon emissions and economic size, therefore curbing their tendencies of gaining economic benefits in the cost of climate change is of significant environmental meaning. However, such effort needs to be performed based on profound understanding of their emission incentives (like international trade) and the feasibility of policy proposals. The authors examined the driving forces underlying changes of China-India carbon embodied trade based on data from 2000 to 2015. The methodology they employed was the Multi-Regional Input-Output (MRIO) model and Structural Decomposition Analysis (SDA) which were not innovative. The major result was that China had been acting as the net-exporter in terms of both carbon embodied and goods in the China-India trade, and in addition the magnitude of carbon trade imbalance exceeded that of goods by a lot, which indicated that China had been sacrificing environmental welfare for economic gains. The imbalance was due to differences in the industrial structure of the two and the roles taken in the globalization by the two [3].

2.2 Carbon Leakage Controlling Mechanism

2.2.1 Carbon Tax (Tariff)

Kuik and Hofkes pointed out that unilateral and regional climate policies are likely to suffer from free-riding and/or carbon leakage, and they suspected that whether the border adjustment measures would be a valid solution from EU ETS's point of view. They utilized a multi-sector, multi-region computable general equilibrium (CGE) model to depict the global economy and examined the effects of such adjustment measures within this theoretical framework. From empirical results they concluded that, firstly such measures would lead to different rates of carbon leakage for different sectors (the iron and steel industry would experience more drastic increases in leakage rate than mineral product industry sector) which would impact sectoral competitiveness in turn; secondly the effect of such measures would be mild from a macro and environmental perspective. Despite of over-simplified assumptions about details of border adjustment measures that the EU ETS can impose, the method of measuring effectiveness of climate policy with CGE models are inspirational. Moreover, Kuik and Hofkes essentially supported the idea that the climate change mitigation cannot be accomplished simply by regional effort[4]. Gros and Egenhofer discussed this matter based on the framework of welfare economics – the "tenet" that taxation (in any form) would cannibalize global economic welfare and cause deadweight loss. However, when incorporating externality effect brought up by greenhouse gas emissions, this rule could be overturned. Gros and Egenhofer argued that taxation by the EU on the CO_2 emissions embedded in imported goods (the "CO_2 content") from countries "without carbon pricing or regulation" would enhance the global welfare. In other words, the positive externality would overweigh the deadweight loss [5].

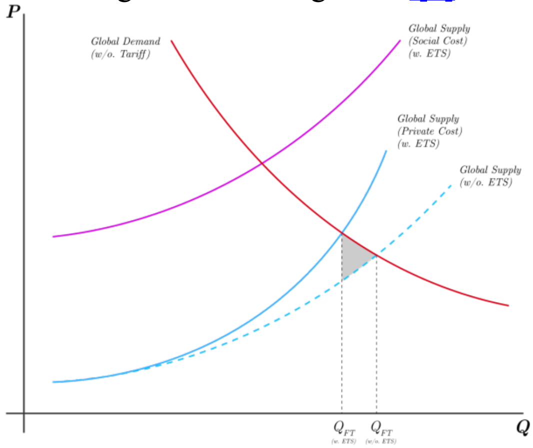

Figure 1.Trade Equilibrium under ETS without Tariff

The economic model behind the EU ETS and (potentially) carbon tariffs is shown in Figures 1 and 2. The gray areas in Figures 1 and 2 represent the deadweight loss of the ETS system and the impact of carbon tariffs on the balance of foreign trade supply and demand.

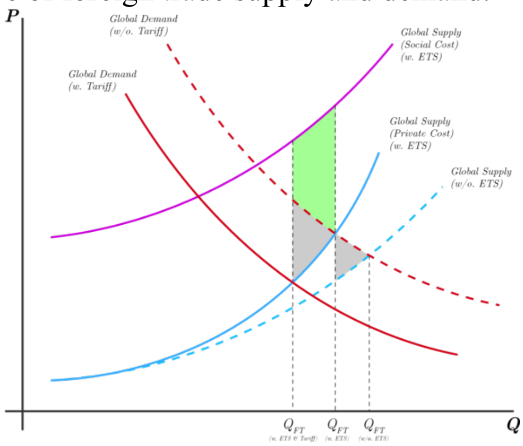

Figure 2 Trade Equilibrium under ETS with Tariff

In Figure 2 we shade positive externality effect of imposing carbon tax as green and by visually inference, we can tell the from a social welfare perspective, the carbon tax can contribute to the total social welfare since the area of green shade is larger than that of the gray one. Acknowledging that the carbon tariff (border measures more precisely) can be designed compatible with the WTO rules as well, Gros and Egenhofer even proposed scenarios catering to the equity consideration in the United Nations Framework Convention on Climate Change (UNFCCC) – i.e., rebating tax revenues based on the level of development for each country[5]. To conclude their discussion, they mentioned imposing export tax on carbon-intense products in international exporters like China and India proposed by some research, which can be considered as "measure of duality" to the import carbon tax [6-8]. However, despite that the externality of imposing such tax is enjoyed by all the human beings, the deadweight loss would be mainly born by these developing countries. Fischer and Fox considered four candidate policies that could complement the unilateral (domestic) greenhouse gas emission regulations – border charge on imported carbon, border rebate for exported carbon, full border adjustment, and GDP-based rebating. The authors employed the method of simulation for high-energy-reliant sectors of three developed economies – the United States, Canada, and Europe Union – and concluded that all four candidates could not lead to reduction in global greenhouse gas emissions for sure, despite that all of them can boost sectoral competitiveness. In addition, they found that the effectiveness of the four complementary policies was sensitive to industrial, environmental characteristics (like gross domestic demand, elasticity of substitution, etc.) of the imposer country and/or the corresponding sector, therefore, it would be difficult to tell which policy would output more enhancement. Empirically speaking, their evidence showed that the full-border adjustment was the most effective choice for the concerning economies in most times [9]. Böhringer, Rosendahl demonstrated that the full border carbon adjustment could be effectively achieved (so long as the carbon tariffs and/or the rebating were not discriminated across importers) by combining Consumption Taxation on carbon-intensive, trade-exposed products and the Output-Based Rebating (OBR). They proved that such combination could improve economic welfare, which would be particularly significant when the OBR had already been imposed on sectors less exposed to carbon leakage. Possible explanations included uncertainty about the exposure, lobbying activities, etc. Based on their arguments, the authors concluded that supplementing the OBR with consumption tax could constitute a robust policy candidate to alleviate the carbon leakage, which possessed the advantage of limiting the risk of detrimental trade disputes compare to the full border carbon adjustment scheme [10].

2.2.2 Carbon Trade

Goulder and Schein investigated three options regarding carbon leakage control – the carbon taxation, the cap-and-trade system, and the hybrid of the two (a cap-and-trade system with price ceiling/floor) [11]. The authors found that the three options shared surprising similarities along dimensions that are beyond what had been recognized (Table 1).

Table 1.Similarities between Carbon Tax and Carbon Cap-and-Trade System

Dimension	Description
Incentive	Identical marginal incentives in terms of emission reduction The similarity is independent of how the allowances are allocated in the cap-and-trade system
Burden Distribution	Carbon tax and cap-and-trade system share similar options along: The extent of free emissions The disposition of revenue due to policy
International Competitiveness	Carbon tax and cap-and-trade system share similar options along: The opportunities for border adjustments The mechanisms for subsidizing carbon-intensive sectors that are exposed to international trades
Rebating Choice	Provisions for rebate may be provided to both carbon tax mechanism and the cap-and-trade system

Moreover, they specified novel dimensions along which the three options were distinct in terms of their impacts (Table 2).

Table 2. Relative Advantages of Carbon Tax, Cap-and-Trade System, and The Hybrid

Dimension	Carbon Tax	Cap-and-Trade	Hybrid
Administrative Cost	Minimum		
Carbon Allowance Price Volatility	Mitigate		Mitigate*
Policy Uncertainty			

Weitzman issue	Address		Address
Murray-Newell-Pizer issue		Address	Address
Leakage from "Nested" Regulation	Mitigate		Mitigate*
Wealth Transfers to Oil Exporters	Mitigate		Mitigate*
Revenue-Neutrality, Promote Broader Tax Reform	Achieve		

Note: 1. * represents that the effect is only valid when price ceiling/floor is introduced; 2. Green shading indicates that the corresponding mechanism possesses relative advantage, and yellow shading indicates conditional relative advantage

Despite that they failed to pick a dominant winner among them, they had reached the conclusion that the pricing mechanism (introduced by either the carbon tax or hybrid option) acted as a positive addition in terms of attractions to the sole cap-and-trade system. The elementary economic logics behind their findings included: first, an exogenous pricing mechanism can help mitigate volatility of "carbon allowance price"; second, it can provide cushion to uncertainties brought up by climate policies; and third, it can help prohibit stakeholders (especially oil exporters) exploiting the climate policies as wealth-transfer channel. Acknowledging that the cap-and-trade system might lack certain advantages brought up by the pricing feature, the authors concluded that all three approaches had the potential as cost-effective, equitable and environmental successful candidates to help reduce greenhouse gas emissions. Deng and Xu built a Multi-Regional Input-Output (MRIO) model to estimate the quantity of embodied carbon traded globally between 1995 and 2009 [12]. To reflect and quantify the changes in scale and structure of embodied carbon trade of four major carbon economies (namely China, India, Japan, and the U.S.), the authors used the Structure Decomposition Analysis (SDA). With empirical records from the World Input-Output Database (WIOD), they found that Japan was replaced by India as one of the "top carbon traders" from 1995 to 2009, while the U.S. and China had held the position. From the industry sectoral perspective, the sectors that had exhibited highest carbon emission coefficients (both direct and total) are Electricity, Gas & Water Supply in current top carbon traders (the U.S., China, India), although the magnitude of those coefficients differed for three economies. Such coefficients could reflect the changes in embodied carbon emission (via imports/exports and/or self-consumption) – smaller coefficients indicated effective reduction in embodied carbon emissions. Based on their empirical evidence, they proposed policy suggestions that the carbon emissions per unit of output should be set as the focus to bring down, and for sectors with high emission coefficients "importing instead of producing" should be considered. In addition, they suggested that low-carbon and energy-efficient technology spillovers should be encouraged. Jevnaker and Wettestad reviewed and examined the "Cornerstone & Flagship" of EU climate policy – the Emission Trading System. They acknowledged the merits and contribution of the system, while spotted several "fatal" crises in its history [13]. The carbon allowance surplus and consequential sagging carbon price in the spring of 2013 raised the suspect of redundancy towards the system because carbon emitters were not actually constrained or adjusting their behaviors under the system back them. Two years later, the proposal of overhauling the system and adapting a more quantitative oriented "market thermostat" i.e., the Market Stability Reserve (MSR) was on the table of the European Parliament – which prevented the ETS from "sinking" (as the flagship) but failed to revive the system. The authors attempted to answer why such "flagship" policy design was that fragile and shine insights on how a more effective carbon trading system could be achieved gradually. The factors proposed by them were rather qualitative, like a more inclusive attitude that the Commission's proposal should embrace (especially towards contradicting views), a combination of "domestic shifts" and "integrative bargaining" that is more eclectic to attract more support among members of the

Council, and so on. Based on their proposed improved EU ETS, the authors suggested that the carbon markets beyond the EU might well learn from the EU's experience and/or need corresponding adjustments. For example, the sizes of types of coalitions and majorities that could adapt reformation should be well assessed before policy proposals. They concluded their work by pointing out that the ETS was at a crossroads. Sun, Xue proposed a novel approach to control carbon leakage to modify existent emission trading systems that could cater to developing economy's circumstances – namely the Dynamic Emission Control Coefficients (DECC) which intended to optimize the carbon allowances allocation scheme. The output of DECC is a continuously dynamic coefficients for each sector/industry to impose emission control. Based on the empirical performance of their method applied to data from Hubei Province of China, the authors argued that the efficiency, fairness of allowance allocation could be improved, room for low-carbon industrial transition could be spared, the ideal balance between competitiveness protection and de-carbonization could be strived, and the most suitable for emission trading systems that can be adopted by developing countries like China [14].

2.2.3 Policy Spillover

The carbon tariff/tax and carbon trade discussed above focus more on the unilateral aspect of carbon leakage controlling mechanisms. In other words, they assume the external environmental factors (including the strategies and/or responses from other countries) are given i.e., exogenously determined. However, the assumption is rarely close to the real-world scenario because those are the significant developed countries that are actively imposing climate related policies, and their decisions concerning production, international trade, etc. cannot be "bluntly" ignored without consequences. Therefore, policy making process regarding carbon leakage is more likely to incorporate game theory by considering counterparts' decisions, which is called "policy spillover" in our context.

Van Asselt and Brewer spotted the international competitiveness and carbon leakage as two interrelated issues in domestic policy affairs and confined the scope of discussion within the United States and the European Union[15]. The former issue was based on the idea that the competitiveness of industries exposed to international competition will be weakened by stricter or more climate friendly policies compared to their international counterparts by Van Asselt and Biermann [16]. While the latter one is a "related yet distinct" concern, because the emission transfer can be attributed to many other factors besides comparative competitiveness. Van Asselt and Brewer contrasted the two issues in U.S. and EU focusing on the "import-related border adjustment measures", elaborated various ways addressing the two issues in two regions, and emphasized the offsetting-measures implementation as the possible middle way [15]. In addition, the authors reiterated the advocate of multilateral agreement on restricting the deployment of border adjustment measures made by Dröge, van Asselt [17]. By extending the restraint to cooperation (including explicit cooperation in the formal international negotiating processes and the form of an international learning process), the authors saw a brighter win-win situation regarding the climate change and economic development.

Monjon and Quirion emphasized more on the compatibility of border adjustments to EU ETS with World Trade Organization (WTO), with particular concern to two configurations – the GATT general regime and the Article XX (environmental exception rule). They assessed the impacts of different border adjustments with a quantitative model – the partial equilibrium model CASE II, where four participant industry sectors (aluminum, steel, cement, and electricity) of EU ETS are modeled. Based on their empirical results, they suggested that border adjustments to both the import and export rules lead to more significant emission reduction than that concerning only import rules. In addition, compared to imposing carbon tax individually, an agreement on building a central allowance distribution system (maybe the EU ETS) and obliging importers to buy carbon allowances universally turned out to be more compatible with the WTO rules and possibly a better choice to control carbon leakage and gross emissions. From a inter-sector perspective, Monjon and Quirion argued that the border adjustment measure might effectively mitigate carbon leakage between countries though, it was expected to cause inter-sectoral carbon leakage – the production of GHG-intensive products in EU would decrease (which was attributed to reduced demand instead of reduced market share) and consequently elevate the cost burdened by sectors within the EU ETS. As a result, the competitiveness of particular sectors might be weakened if they had not possessed the bargaining power over downstream sectors. Based on all insights they found, Monjon and Quirion recommended a policy combination (a scenario) which was an optimum regarding carbon leakage controlling efficiency and WTO compatibility – a border adjustment to EU ETS that is allowance-based, covering both imports and exports and using EU product-specific benchmarks (to resolve the weakened sector competitiveness issue) [18].

Böhringer, Lange argued that pricing discrimination in the name of carbon leakage control might become "a beggar-thy-neighbor policy" to exploit terms of trade when the policy scope was confined domestically. The authors proposed a theoretical framework to distinguish the leakage controlling and terms-of-trade motives for "emission price differentiation", and quantitatively assessed the existent unilateral climate policies. The essence of the framework is a decomposition reflected by terms of a general equilibrium model (although the analytical model concerns only two economies for simplification). They found that the leakage controlling intention of pricing discrimination merely yielded minor increase in efficiency comparing with the uniform pricing mechanism. And similarly, the terms-of-trade motivation exhibited even lesser potential for meaningful "strategic reduction burden shifting". Based on their empirical findings, they arrived the conclusion that the uniform emission pricing mechanism as "the simple first-best rule" was not necessarily dominated by sectoral pricing discrimination regarding unilateral climate policy design, and therefore remained as a practical guideline [19].

2.2.4 Impact on International Trade

Zhou, Gong built a mathematical model to depict and explore the influences of carbon tariff (imposed on traded goods from "unregulated countries" to "regulated countries", where the "regulated" meant the country had imposed carbon emission reduction policies/rules) on the cross-border supply chain. The model can be categorized as a mixed integer nonlinear programming model. The authors performed an empirical "experimental" study with their model towards an electronic multinational producer based in Taiwan (maybe TSMC). Their outcomes suggested the circumstances when carbon tariffs could spur a corporation to take emission reduction actions without local climate policies – sole carbon tariff could not motivate non-member manufacturers to reduce their emissions, while accompanying the tariff with capacity restriction could validate its purpose. In turn, comparing to sole capacity restriction, the combination with carbon tariff can boost the economy of scale for producers i.e., it would be cheaper to expand capacity when carbon tariff was imposed [20]. Böhringer, Carbone focused on the economic and environmental impacts of carbon tariff. The authors found that the tariff could reduce out-border carbon emissions though, it would fail improving the efficiency (economic-ness) of unilateral climate policies worldwide despite of how delicate the tariff rates were designed. If the scope of taxable emissions is extended to the full content of carbon from embodied carbon, despite that the carbon leakage from unilateral OECD policies would be effectively mitigated, the global cost of emission reduction would even increase rather than decrease. From the distributional point of view, they argued that the major consequence of carbon tariffs was the transfer of emission reduction responsibility (burden) from developed economies (like OECD countries) to developing ones, and as a result the existent income gap (inequalities) would be exacerbated [21]. Hotak, Islam resolved the mechanism beneath the relationship between carbon trade balances and carbon emissions in the context of globalization and fragmented manufacturing (international specialization). The methodology they used was to apply a panel-pooled mean group-autoregressive distributive lag (PMG-ARDL) model to a panel data of 58 countries over the period of 1990 to 2014. Their model revealed a positive correlation between carbon trade balances and carbon emissions for high-income economies. The relationship revealed the motivation of high-income economies to displace production units to trading partners and/or outsourcing carbon-intensive procedures offshore – because they can effectively reduce the domestic carbon emission (in other words carbon leakage). However, the authors found no significant evidence that low-income economies could enjoy similar privilege [22].

Based on their finding, they argued that high-income economies (particularly carbon embodied importers) should bear more responsibility for climate change and advocate environmentally friendly technology spillovers in the process of outsourcing carbon emissions.

3. Conclusion

3.1 Key Findings

This article reviewed major academic works concerning the topic of carbon leakage and its controlling mechanisms published during the last decade. Clear patterns regarding transitions of their research focus and methodologies have emerged during the review process: first and foremost, the perspective has altered from unilateral (domestic) point of view to the multilateral view; second, the focus has moved from the developed world (the EU in particular) to the developing world (like China and India); thirdly, the research method has incorporated more and more quantitative models to gain insights from multi-dimensional data (compared to previously more qualitative-oriented analysis).

At the time of this writing, the pioneering and flagship carbon emission reduction schemes like the EU ETS with MSR have mostly entered their mature phase. By reviewing the evolvement and debates during their development process, we hope to shed light on what can be borrowed, what can be avoided and what requires more trial-and-error attempts to modify and adapt for developing economies like China.

3.2 Limitations and Future Study

Since the proposal of climate change mitigation in the 1990s, the amount of scholar works on this matter is vast, I failed to incorporate each and every work in this article due to the limitation of time and length. Therefore, this work is worth of being comprehensive yet not exhaustive. Moreover, despite that such mitigation has been agreed upon and the research have evolved to this day, debates regarding responsibility allocation, opportunity costs of economic expansion have not been settled on, and this work does not contribute direct resolution or policy proposal related to those issues. As the "deadline" of effectively reduce greenhouse gas volume is drawing nearer and nearer, much more endeavor beyond the academic field is called. On the other hand, the effects of COVID-19 pandemic and more recent geopolitical conflict between the Russia and Ukraine are not well incorporated and reflected in this work either. When human beings are confronted with a more acute threat, how large the concession we could made to tolerate short-term laxer climate policy (if any) and how the climate mitigation plans should be adjusted to reflect such impacts are worthy question to be well answered.

Furthermore, recent geopolicital matters inspired us that international rules and systems can be weaponized to sanction certain economies in today's highly globalized world. Therefore how to balance the fairness of cross-border climate rules and efficiency of controlling carbon leakage is another direction that future works can go.

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