Climate Policy

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tcpo20

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To cite this article: Jiarui Zhong & Jiansuo Pei (2023): Carbon border adjustment mechanism: a systematic literature review of the latest developments, Climate Policy, DOI: 10.1080/14693062.2023.2190074

To link to this article: https://doi.org/10.1080/14693062.2023.2190074

CLIMATE POLICY
https://doi.org/10.1080/14693062.2023.2190074

Carbon border adjustment mechanism: a systematic literature review of the latest developments

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ABSTRACT
Carbon border adjustment mechanism aims to level the playing field and reduce carbon leakage through import taxes and/or export subsidies based on the carbon content for products from countries with different levels of carbon policy stringency. The introduction of an EU carbon border adjustment mechanism (CBAM) has triggered a lively debate on its potential impacts, especially among developing countries. In fact, introducing CBAM is not a new idea; researchers in fields of economics and law have investigated this policy over the last decade. Against this backdrop, this study conducts a literature review of the most recent economic studies of CBAM and provides an exhaustive synthesis of this literature. We employ the so-called 'Preferred Reporting Items for Systematic Reviews and Meta-Analysis' approach (PRISMA), which includes an exhaustive screening of studies. Specifically, we identified 97 relevant studies on CBAM from 2004 to 31 August 2021, and conducted descriptive and content analysis of these. Our content analysis highlights the potential impacts of CBAM in terms of its effectiveness across 3 policy objectives: protecting fair competition; reducing carbon leakage; and limiting global welfare costs. We synthesize findings on how policy design and characteristics of an economy lead to different levels and types of effectiveness of a CBAM, and we contrast alternative policy designs across various objectives. Armed with this systematic review of the literature, we spell out insights and challenges in formulating effective CBAM polices. This review thus offers evidenced-based guidance for the policy design of a CBAM and a foundation for further research.

Key policy insights:

- There is no one-size-fits-all approach to design and implement CBAM to tackle competitiveness and carbon leakage; policy design and characteristics of the economy matter.
- According to the effectiveness of CBAM across the 3 policy objectives, alternative policy designs should account for the coverage of trade, of sector(s), and also the means to determine carbon content of traded commodities, the use of revenues collected through CBAM, and the adjustment price.
- In formulating sound CBAM policies, competitiveness, carbon leakage and welfare evaluation are central economic concerns; however, consistency with the latest international climate policy architecture and fairness issues should also be addressed.

ARTICLE HISTORY
Received 30 June 2022
Accepted 7 March 2023

KEYWORDS
Carbon border adjustment mechanism; systematic literature review; competitiveness; international trade; carbon leakage; policy design

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Supplemental data for this article can be accessed online at https://doi.org/10.1080/14693062.2023.2190074 .

1. Introduction

Global cooperation and engagement, and current policies and actions to address climate change are inadequate to attain the goals of the Paris Agreement (Olhoff & Christensen, 2020). A major reason is that countries that take the lead in implementing carbon reduction policies risk economic disadvantages. The first issue is that policies that preserve a stable climate are prone to free-rider problems, which are likely to emerge whenever one party can enjoy the benefits of a public good without paying for its production.[1] Other concerns are that adopting a unilateral climate policy might entail a loss of competitiveness and carbon leakage. The latter happens when production is transferred to regions with laxer emission constraints, thus resulting in increasing emissions in those countries and offsetting the emissions reduced in countries with tighter emission budgets.

Instruments to mitigate these concerns and enhance global participation in emission reduction have long been debated. Potential policy instruments are international sectoral agreements, cost containment measures, free or output-based allocation of allowances, and what has been termed as Carbon Border Adjustment Mechanism (CBAM), which is the focus of this study. CBAM, also called carbon border tax or carbon tariff in the literature, refers to border adjustments to level the playing field for products from countries with and without carbon regulations, which thus face different carbon prices (Cosbey et al., 2019, p. 3). In the past 15 years, many studies have focused on the feasibility and effectiveness of CBAM. The commonly discussed issues are CBAM's effectiveness in reducing carbon leakage and preserving competitiveness, its strategic purpose, legal and political feasibility, and appropriate policy design. The competitiveness impact is also referred to as distributional impact and shifts the burden of climate policy from the implementing country to others. We refer to this as preserving competitiveness from the perspective of the implementing country.[2]

We have conducted a systematic review of the burgeoning literature on CBAM from an economic perspective. It focuses on answering the following questions. Will CBAM be an effective policy instrument in these two perspectives? More broadly, will CBAM be regarded as an evidence-based scientific policy, and what kind of policy design will be most effective? This study aims to provide a comprehensive and up-to-date overview of the knowledge on this vehemently debated policy instrument. More specifically, it presents a descriptive analysis that infers important trends and features of research in this topical area and a content analysis that reviews and synthesizes the research findings on the questions posed above.

To our knowledge, three review articles with similar objects are available. Two of them are included in our database, while the other was published after we completed a literature review for this study. The first literature review synthesized the results of 25 quantitative studies that used computable general equilibrium (CGE) modelling from 2004 to 2012 (Branger & Quirion, 2014). Another narrative review summarized economic and legal literature on CBAM in a narrative paradigm and discussed how to design and implement an effective and legitimate CBAM (Cosbey et al., 2019). Finally, a recently published review also falls in the narrative paradigm on the potential environmental and economic impacts of CBAM measures (Böhringer et al., 2022). In contrast, this study presents a systematic literature review. The advantage of this approach over a narrative literature review is that it uses the scientific methods of searching, appraising and synthesizing literature to minimize systematic errors (biases), and results in relative higher comprehensiveness, transparency, and rigorosity (Petticrew & Roberts, 2008). This study is an attempt in this direction.

2. Method: the preferred reporting items for systematic reviews and meta-analysis (PRISMA)

The systematic literature review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) approach (Page et al., 2021). The PRIS part of this approach guide

[1]The externality problem can be dated back to the classical discussions, for example, Pigovian tax in Pigou (1920) and Coase theorem in Coase (1960). A thorough discussion concerning this line of research is beyond the scope of this study.

[2]Noting that it is not a normative statement concerning whether the protection of competitiveness is justified. The question of whether CBAM should be used to protect competitiveness, especially in developed countries, is controversial. For example, given historical responsibility and capacity, developed countries are often regarded to be more responsible for emission reductions. Also, in legal literature, such as the World Trade Organization compliance discussions, it is emphasized that CBAM should not be applied with the goal of protecting competitiveness for equity considerations.

researchers to develop comprehensive plan and search strategy for literature a priori. Here, we search articles in two widely used databases: Web of Science (WoS) and Scopus, which are among the leading databases that cover peer-reviewed scholarly literature of virtually every discipline, and provide an ideal pool of literature resources. The articles included were according to the following pre-defined eligible criteria: (i) appeared in economic scholarly journals indexed by the Social Sciences Citation Index; (ii) full-length and published in English, while excluding all other types such as research notes, editorial, comments, conference papers and reviews and (iii) directly related to CBAM policy. Specifically, we looked for all articles in the final stage with keywords 'carbon,' 'border adjustment,' 'tariff,' or 'border tax' in the title, abstract and/or keywords. The search queries in terms of key words were 'TITLE-ABS-KEY (carbon AND (border AND adjustment OR tariff OR border AND tax))' in SCOPUS, and 'TS = (Carbon AND (border adjustment OR tariff OR border tax))' in WOS. Additionally, we restricted document type to 'Article,' language to 'English,' and subject area to 'Economics,' with no restriction on the publication date. Our final search was conducted on 5 September 2021.

Subsequently, we exported the title, abstract, keywords, authors' name, affiliation, journal name and publication year to an MS Excel spreadsheet. In the first round of screening, two independent researchers carefully reviewed the titles and abstracts of the records. Only articles with abstracts indicating subjects completely irrelevant to CBAM were excluded. Those whose relevance could not be determined accurately were retained to the later stage of full-text review. In this round, we kept our inclusion criterion broad enough to ensure that no relevant studies got inadvertently excluded.

At the full-text review stage, we reviewed the full text to further determine whether CBAM was the research subject. As we attempted to provide an exhaustive literature review, we excluded articles where CBAM was not the primary research subject or, in terms of policy comparison studies, one of the primary research subjects. Regarding inclusion and exclusion, the decisions were explicit, and the reviewers did not encounter disagreements. While reading the full text, we added the following items and records for each article for later use in the descriptive analysis: methodology employed, main dataset, type of CBAM instrument studied, coverage (e.g. industry, emissions, implementation region, target region), emissions default, use of revenue, the level of CBAM price, effectiveness in preserving competitiveness, reducing carbon leakage and lowering global welfare costs of climate policy. For articles that adopted qualitative analysis and literature review, if they generally discussed various policy designs or did not specify a particular policy design, they were recorded as 'not applicable' in the corresponding entry. Similarly, articles that did not focus on effectiveness were recorded as 'not applicable' in the corresponding entry. For quantitative analyzes and simulations, if multiple policy designs were discussed and simulated, each design and the corresponding effects were documented. In this process, one reviewer extracted and recorded the data, and the other reviewer double-checked the coded data.

3. Descriptive statistics

Figure 1 summarizes the literature screening process described above. Our initial search in the database found 377 articles, of which 252 and 125 were from Web of Science and Scopus, respectively. Of these, 58 duplications were removed, and two articles were excluded as they were unavailable online. Of the remaining 317 articles, we discarded 200 articles irrelevant to CBAM. Subsequently, we read the remaining 117 articles in full and removed 20 irrelevant articles. Finally, 97 articles from 49 journals were screened for this study.[3] Those articles were dropped solely because their content was irrelevant to CBAM. For example, of the 161 articles removed from WOS, those containing 'carbon' and 'tariffs' falling in the trade area and 'carbon' and 'feed-in tariffs' in the new energy area totaled 101 articles.

Regarding the time trend (see Figure A2 in the Appendix in Supplementary Material), studies on CBAM emerged mainly from 2010 and moved in step with discussions concerning policy instruments that addressed competitiveness, carbon leakage and economic welfare issues. Relevant studies were most frequently published between 2010 and 2013 – approximately 44% – probably because the period coincided with the first commitment period of the Kyoto Protocol (2008–2012). The Kyoto Protocol sets binding national targets but leaves the autonomy to countries in formulating domestic climate policy. Against this backdrop, the largest

[3]For the complete list of 97 articles, please see the Appendix.

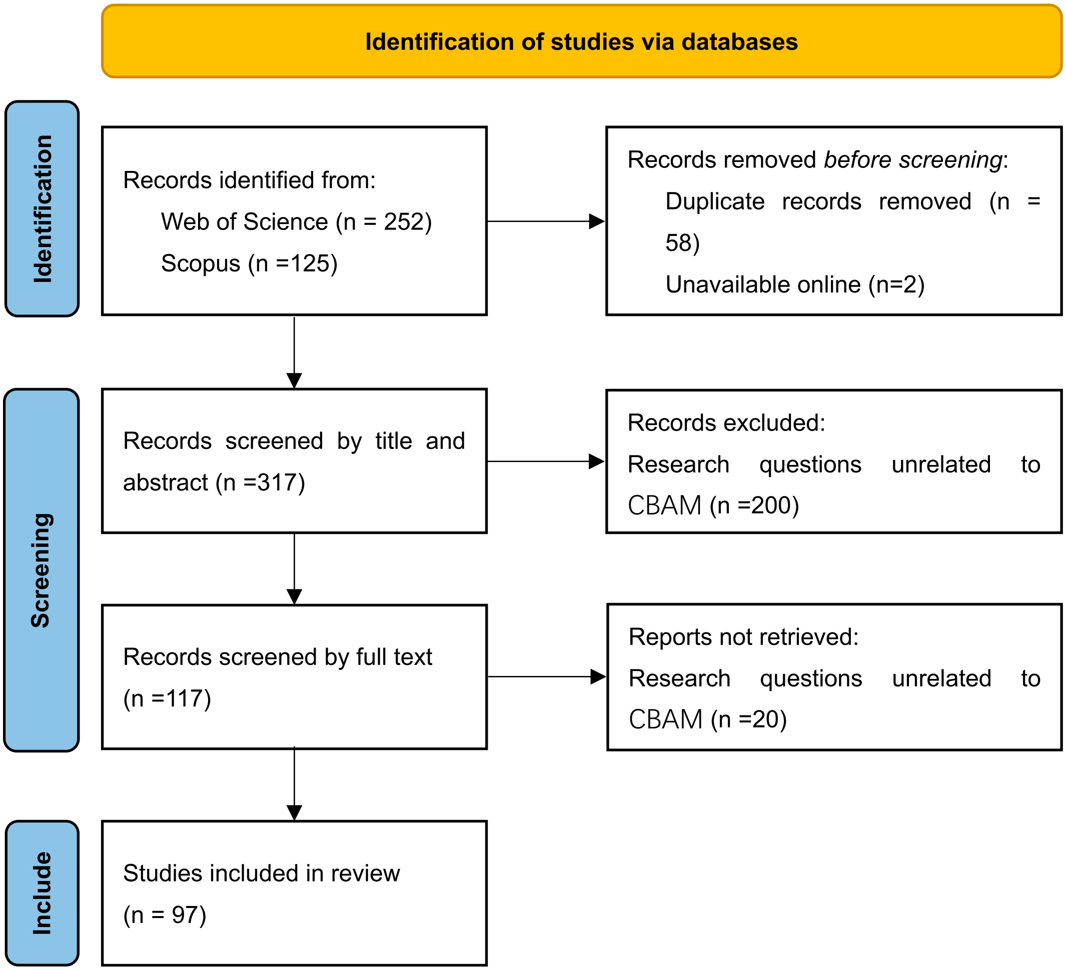

Figure 1. Flow chart of selection process.

Emission Trading System (ETS) was introduced by the European Union (EU) to achieve its binding abatement target. The introduction of such a unilateral carbon pricing policy triggered the heated discussion on CBAM as a policy tool to deal with the potential carbon leakage.

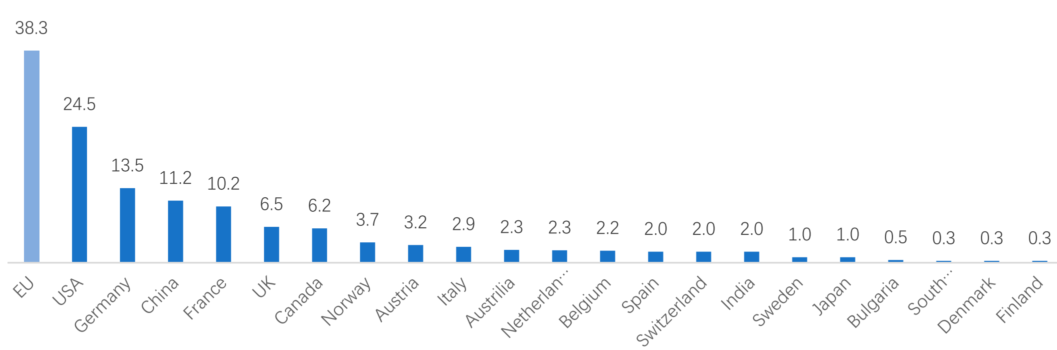

Figure 2. Number of publications by region/country. Note: Articles are credited on a fractional-count basis (i.e. for articles from multiple countries or economies, each country or economy receives fractional credit based on the proportion of its contributing authors).

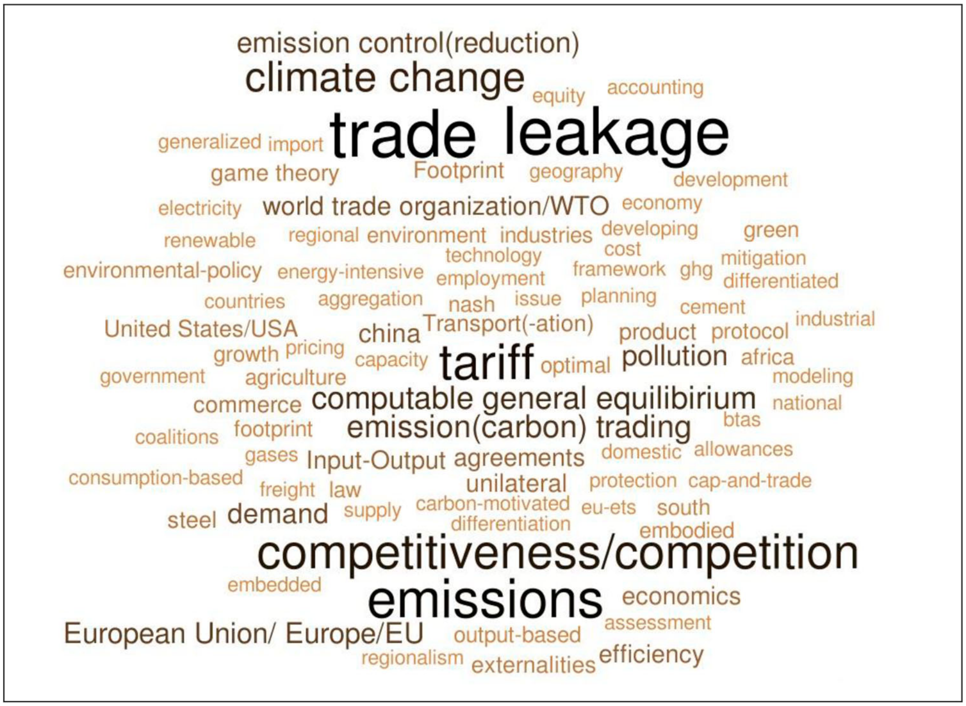

Figure 3. Word cloud of keywords in CBAM research. Note: Only words or phrases that occur more frequently than twice are shown. Keywords used to search the literature itself are not shown such as carbon border tax and carbon border adjustment. The word cloud is generated through WordItOut.com.

Figure 2 shows the counts for these 97 articles by authors' region/country of publication. The most attention to and interest in CBAM is found in Europe and the United States. The EU – one of the first advocates and practitioners – contributed more than one-third of the total. A breakdown by country shows that most of these studies are from the United States and Germany, while perspectives from developing countries except China, which are usually stakeholders of any CBAM measures, are disproportionately represented. Such unbalanced diversity in CBAM studies could underlie the lack of research-based consensus in the international discussion on CBAM and the controversies regarding its fairness. In addition, the scenario of developing countries also implementing CBAMs after a follow-up launch of their carbon pricing mechanisms has not yet been well discussed, but should.

Keyword analysis shows that carbon leakage and competitiveness are the issues of most concern in the CBAM studies (Figure 3). This information backed up our choice of objectives to evaluate CBAMs effectiveness in the later section. The EU and the United States appear among the most frequent keywords. Also, certain methods commonly used in the research, such as computable general equilibrium and Input-Output Analysis, appear in the word cloud.

Table A2 in the Appendix provides statistics on methodologies used in these studies. Mathematical and simulation modelling were the most used methods (61.22%) for CBAM studies to examine the impact of CBAM on competitiveness, carbon leakage and social welfare. Among them, the most adopted is the CGE model (used in 41 studies). Input-Output (IO) analysis was employed in eight articles. Notably, while the IO model often assumes exogenous final demand,[4] investigations using this approach focus more on accounting the scope of carbon emissions covered by CBAM and its resulting adjustments. 35 studies used theoretical approaches. Among them, 21 were based on a qualitative analysis, which broadly elaborated on the rationale of using CBAM, the policy design, theoretical effectiveness, administrative feasibility and its World Trade

[4]See Ward et al. (2019) and Zhong and Pei (2022) for useful extensions.

Organization (WTO) compliance. These articles supplement the examination of the effectiveness of CBAM using mathematical models, and tackle the practical, ethical and legal challenges of CBAM. Additionally, 13 articles employed game-theory models. They mainly illustrated the strategic implications of the CBAM – its indirect impacts on global competition and cooperation in the context of climate change. Finally, two articles were literature reviews – a meta-analysis and a narrative review. For more descriptive statistics, please see the Appendix.

4. Content analysis

In general, CBAM research has undergone a development from focusing on conceptualization and feasibility to examining concrete implementation and policy design. Prior to 2012, over half of the research on CBAM policy was qualitative and discussed the operational mechanisms, potential impacts, WTO-compliance, administrative plausibility and public acceptance of CBAM. In contrast, contemporaneous quantitative studies have attempted to quantify the impacts of CBAM and answer the question of whether this instrument is effective or not. Subsequently, later studies began to address the practical challenges of CBAM through alternative policy designs. For example, how can CBAM be designed to be consistent with WTO-regulations; how can carbon content calculations be simplified without compromising effectiveness; and how to alleviate developing countries' concerns about fairness? Thus, this branch of literature has moved towards a more diverse, specific and practical direction. These studies have provided more evidence-based guidelines for the practical implementation of CBAM.

We synthesized the contributions of 97 articles, primarily in the light of their conclusions, on the following issues: What are the effects of CBAM, and what are the factors that determine the magnitude of its effect? From an economics perspective, the most pressing concern in studies of CBAM is its effectiveness in promoting fair competition, in curbing carbon leakage and in improving global welfare. Therefore, we highlighted the effectiveness of CBAM across these three dimensions. Additionally, 77 studies that quantify the potential effects of CBAM, in different designs and/or are being implemented by different countries, provide direct theoretical evidence to answer the questions given above and are a major support for the policy implications derived in this study. For the other 22 studies, these are qualitative; they offer a range of valuable insights as well, as outlined below (e.g. see discussion 4.3).

Depending on how the impacts develop, CBAM's effects can be classified as direct and indirect. The direct effects are variations in market outcomes caused by (relative) price changes due to CBAM implementation, such as reducing competitiveness loss and carbon leakage triggered by unilateral climate policies (Anouliés, 2015; Keen & Kotsogiannis, 2014). Indirect effects refer to CBAM acting as a threat that causes countries to enhance their climate ambition in terms of inducing economies to join the climate club or promote a more stringent carbon policy. That CBAM can influence affected countries to adopt emission controls of their own is also referred to as strategic value (Böhringer et al., 2016).

Many studies (56 of 77) address the direct effects of CBAM (Böhringer et al., 2012a; Kuik & Hofkes, 2010). The method of analysis is comparative statistics: comparing two different economics outcomes, the equilibrium before and after implementing CBAM, or comparing the performance of different CBAM. The most common design is that the presence or absence of CBAM is the only variable that differed between two scenarios or control groups. The divergence in economic outcomes, such as GDP and trade volume between the CBAM and non-CBAM scenario are ascribed to the direct impacts of CBAM. Comparative statistics are useful to estimate the direct effects of CBAM. Nonetheless, such methods do not consider interactions among countries. How would the affected countries respond? Do they retaliate, raise domestic carbon price, and seek an exemption, or do nothing? In fact, comparative statistics consider only the scenario where affected countries do nothing.[5] However, if CBAM, after its announcement and before its implementation, induces countries to strengthen their carbon policy, it is different from the direct effect. Therefore, studies on the direct and indirect effects of CBAM are complementary to each other.

[5]Recall that the only difference between the two control groups is the presence or absence of carbon border adjustment, and that countries receiving CBAM cannot adjust their domestic carbon policy or take other measures.

4.1. On CBAM's indirect impacts

Studies that examine indirect effects typically employ game-theoretic models. Such models allow affected countries to have a chance to decide their response strategically (stage 2) after CBAM is announced (stage 1) and before it is formally implemented (stage 3). Response options are raising domestic carbon price to the level of the CBAM-implementing country, doing nothing, or retaliating with tariff measures. An affected country decides its response by comparing gains and opportunity costs from backward induction. We identified 11 papers in this stream; all those supporting CBAM have a strategic value in either promoting abating efforts or increasing participation and stability in global climate treaties (Al Khourdajie & Finus, 2020; Anouliés, 2015; Böhringer et al., 2016; Eyland & Zaccour, 2012, 2014; Hecht & Peters, 2019; Helm et al., 2012; Helm & Schmidt, 2015; Mason et al., 2015; Sanctuary, 2018). It is because the CBAM announcement causes affected countries to lower their expected payoff of staying out of the climate coalition as a free rider.

Yet, this strand of literature has handled CBAM design details and the carbon content accounting relatively coarsely – the game benefits are sometimes hypothetically assumed or simply set to correlate positively with the trade volume. Therefore, these studies cannot anticipate how various countries in the real world would respond. Böhringer et al. (2016) filled these gaps and used the CGE model to simulate the game payoffs for each country and applied them in a game-theory model. They arrive at a more contextual conclusion that CBAM would induce China and Russia – two major carbon emitters – to adopt stricter carbon policies. However, other developing countries prefer to retaliate.

Finally, the adoption of different policy designs and some economic factors may also have implications for the strategic value. It is because how threatened CBAM may appear is related to its direct impacts and the latter could be determined by policy design and certain other factors. However, this strand of literature, with its extremely simplistic policy design and economic setup, does not allow us to compare how different policy designs or structural characteristics of the economy affect the strategic value. A few implications can be derived from how direct effects vary given the different policy design and distinct economic characteristics of the implementing region.

4.2. On CBAM's direct impacts

We identified a total of 56 quantitative studies on direct impacts. They often vary in policy designs and examine in detail how economic characteristics of the region make a difference in the impact of CBAM. These investigations allowed us to ascertain how different economic parameters and policy designs determine the effects of CBAM.

At first glance, it appears that there is no consensus in academia on whether CBAM policies are effective in terms of reducing carbon leakage and preserving competitiveness. Most simulations based on economic-theoretical models find CBAM to have some effect, while a few consider it to have a weak or even no effect. Regarding fair competition, 25 of *ex-ante* 28 studies addressing this issue agree that CBAM can partly restore competitiveness loss caused by unilateral carbon policies.[6] Regarding the anti-leakage effect, 21 of 24 *ex-ante* studies find that CBAM reduces carbon leakage.

Böhringer et al. (2012a) conducted a comparison study of 12 models on the efficiency and distributional impacts of CBAM. The mean of the estimates from 12 different models was used to provide a more robust estimate of CBAM's impact. The competitiveness impact of CBAM – which the authors call the redistribution effect – is evaluated as drastic. The authors find that the burden sharing ratio measured in percentage GDP loss for the coalition over the percentage GDP loss for the non-coalition amounts drops from 3:1 in the reference scenario to 1:1 for the case of CBAM. The burden borne by the latter is markedly elevated. CBAM is concluded to be effective in terms of reducing carbon leakage. The carbon leakage rate is defined as the change in foreign (non-coalition) carbon emissions versus domestic (coalition) emission reductions. In the scenario without

[6]Noting that there is no unambiguous definition of competitiveness in the literature. Usually, the deterioration of economic indicators such as export volume, production, profitability, or GDP is seen as a deterioration of competitiveness. To synthesize the literature, four indicators were used in this study as indicators of competitiveness: export volume, output, profitability, and GDP. A CBAM causing any of them to change is regarded as competitiveness impact, which refers to whether it causes a variation in export volume, output, profitability, or GDP.

CBAM, the carbon leakage rate ranges from 5 to 19% (mean 12%), while in the scenario with CBAM, the carbon leakage rate ranges from 2 to 12% (mean 6%). The meta-analysis conducted by Branger and Quirion (2014) synthesized 25 studies on the effectiveness of CBAM on reducing carbon leakage and estimated that the typical range of carbon leakage rate estimates are from 5 to 25% (mean 14%) without CBAM, and from 5 to 15% (mean 6%) with CBAM. In most cases, CBAM's competitiveness impact and effect in reducing carbon leakage is considered noteworthy (Banerjee, 2021; Bistline et al., 2020; Böhringer et al., 2018; Böhringer et al., 2021; Burniaux et al., 2013; Dong et al., 2015; Fouré et al., 2016; Huang et al., 2021; Larch & Wanner, 2017; Li et al., 2013; Mattoo et al., 2013; Mickibbin et al., 2018; Schinko et al., 2014; Winchester, 2018; Xu & Hobbs, 2021).

Several studies have established that CBAM's effectiveness can also be very limited, that it is not warranted even after being introduced, given the considerable implementation costs, equity and political concerns (Antimiani et al., 2016; Kuik & Hofkes, 2010; Siriwardana et al., 2017). For some economies, competitiveness benefits of implementing CBAM can be reversed, both on an industrial level (Liang et al., 2016) and a national level (Böhringer et al., 2015).

This enumeration of the findings leaves an impression of disagreement among researchers. On a closer inspection, however, these differences in opinion might be explained to some extent by the design of simulated scenarios such as policy design and distinct economic characteristics of the implementing region. Therefore, understanding how these variables affect the potential effects of CBAM is extremely important in discerning its mechanisms.

We first elaborated on how the economic structure of the region influenced the effectiveness of CBAM. In the case of competitiveness protection, CBAM works through changing relative prices between domestic products and imports. Raising relative price of imports generate the positive competitive impact of CBAM. The purpose of CBAM is not to create competitiveness for the implementing country but to restore its competitiveness that gets lost due to unilateral carbon policies. This emphasis is made here because trade policies that create competitiveness for domestic products are incompatible with WTO rules. The key for CBAM to be compliant depends on the fact that imports receive no higher adjustment for carbon emissions than the cost of carbon borne by domestic products under domestic climate policies. Simultaneously, CBAM can have negative competitive impact through supply chains. When a domestic production relies largely on imported intermediate goods and the price of imported intermediates rises because of CBAM, domestic price can go up if no cheaper substitute can be found. This situation makes domestic products relatively expensive and therefore, constitutes a negative competitive effect.

In terms of the positive competitiveness effect, determining characteristics can be carbon content in the imported goods, price elasticity of demand, and the degree of trade exposure (import rate). For the negative competitive effect, the parameters that boost the cost pass along the supply chain and cut demand for now pricier domestic products are crucial. Studies identified several parameters that amplify the negative competitive impact and reverse the total effect of CBAM, such as high trade exposure, high composition of embodied emissions in production, and low substitutability of intermediate inputs (Bassi & Yudken, 2011; Böhringer et al., 2015; Liang et al., 2016). Yet, the fact that most of the literature found the effect of CBAM to be in the positive domain means that the spectrum in which CBAM is effective is relatively wide.

What determines the effectiveness of CBAM against carbon leakage? Theoretically, carbon leakage can go through multiple channels – the competitiveness, energy market, income and technology spillovers channels (Dröge et al., 2009). Therefore, the effectiveness of CBAM in preventing carbon leakage is largely related to its effectiveness in restoring competitiveness. However, the two are not exactly equivalent. A possible scenario in which the two diverge is that the implementing country reduces imports from high-emitting countries and increases consumption domestically through CBAM. In this dimension, CBAM is effective in preserving competitiveness. However, if the exporting country shifts to supply unregulated markets and expands the sale of carbon-intensive products, and consequently, its total emission increases, then CBAM would not reduce carbon leakage. Studies have also shown that it is possible that CBAM leads to increased production of carbon-intensive products in exporting countries and results in higher total carbon emissions, for example, in China (Fang et al., 2020; Jakob et al., 2013). Finally, CBAM addresses most carbon leakage arising from the competitiveness channel and is ineffective against the leakages from other channels. Even here, CBAM cannot guarantee that the leakage from the competitiveness channel is eliminated. It depends on (i) how likely exporting countries could find alternative markets, and (ii) to which extent the reshuffling occurs (Böhringer et al., 2016).[7] The likelihood of reshuffling occurring is related to policy design, which is examined later.

Another element that is identified to affect CBAM's effectiveness is the size of the abatement coalition increases. It is demonstrated that as the number of countries engaged in global climate action increases, the direct effect of CBAM and strategic value will decrease (Böhringer et al., 2014). The implication here is that CBAM may be appropriate only as a provisional policy.

Zhang et al. (2017) demonstrated that the more countries that implement such a universal CBAM, the larger will be the border crossing frequencies, and the more severe the problem of multiple taxations, which reduces CBAM's cost-effectiveness. Finally, exemption might also be granted to low-income countries for equity considerations and to comply with the burden-sharing principle of Common But Differentiated Responsibilities (CBDR) (Clarke, 2010).

4.3. For policymaking: how to design a practical and effective CBAM?

There is no one-size-fits-all approach to design CBAM to tackle competitiveness and carbon leakage, hence, policymakers face the subtle problem of how to design CBAM policies that conform to their economic realities while delivering desired outcomes. Indeed, the effectiveness of CBAM is largely related to its design, which includes components such as import/export coverage, product/sector/country scope, determined carbon content, revenue utilization and adjustment price among other considerations (Cosbey et al., 2019). Synthesizing evidence from studies that simulated alternative CBAM policy designs, we rank preferable ones according to their effectiveness on 3 objectives, namely, protecting competitiveness, reducing carbon leakage and limiting global welfare costs, respectively. By so doing, we can provide a guidance for policymakers in designing CBAM. The results and background literature are listed in Table 1.

4.3.1. Import/export coverage

CBAM can take the form of import tariff, export rebate, or both (full CBAM). Our review shows that the most studied design is import tariff, followed by full CBAM, whereas export rebate is rarely explored (see Table 1). Most quantitative studies comparing full CBAM and import-only CBAM reveal that full CBAM is more effective in maintaining competitiveness and anti-leakage, yet the difference is found to be modest. For instance, Böhringer et al. (2012a) concluded that in contrast to the import-only CBAM, full CBAM is of 'secondary importance for effectiveness and distributional effects.'

Regarding export-only CBAM, the findings on its effects are inconclusive. Fischer and Fox (2012) found that the competitiveness impact of export-only CBAM was less than that of full CBAM but larger than that of import tariffs. However, Liang et al. (2016) held that implementing export tax rebates could maintain China's competitiveness and was slightly more effective than full and import-only CBAM. The main reason is that China suffers from the remarkable negative competitiveness impact of CBAM as it has a large amount of processing trade, is extremely dependent on imported intermediate goods, and has low bargaining power in the international market. In this case, a CBAM adjustment for imports would cause China's exports to suffer negative competitiveness. In contrast, an adjustment for exports would avoid this problem. Siriwardana et al. (2017) had similar findings. The policy implication here is that the effects of the policy design and the economic characteristics mentioned earlier on the effects of CBAM are interactive, and in some extreme cases, the ranking of the superiority of different policy designs on a given objective may be reversed because of the economic characteristics.

We found inconclusive opinions in the literature on how CBAM measures affect global welfare. Lanzi et al. (2012) found that CBAM results in higher welfare costs compared to connecting to the global carbon market, and a full CBAM causes higher global welfare costs than CBAM only on imports. In contrast, Mattoo et al. (2013) demonstrated that the welfare costs of a full CBAM is lower than import-only CBAM. Similarly, Böhringer et al. (2014) suggested that CBAM reduces the cost of fulfilling mitigation targets globally, and full CBAM achieves a given mitigation target at a higher cost-effectiveness than import-only CBAM.

[7]Reshuffling is where product is redistributed among buyers in different regions such that regulated regions receive low-emitting products while unregulated regions receive high-emitting ones.

Table 1. Synthesizing the effectiveness of policy design on CBAM across various policy objectives.

		Objectives		
		1. Protect Competitiveness	2. Reduce carbon leakage	3. Reduce global welfare costs of climate policy
A. Coverage		**Full ≽ Import** [10; 55; 71; 59; 48; 77]	**Full ≽ Import** [41; 48; 53; 55; 59; 71; 77]	**Full ≽ Import** [41; 48]
		Full ≽ Export ≽ Import [63] **Export ≽ Full ≽ Import** [31; 32]		**Import ≽ Full** [59]
		(1) There is a broad consensus that full coverage CBAM protects competitiveness (+) & limits leakage (+) better than CBAM on imports only. (2) In terms of protecting competitiveness, the effects of CBAM on exports only compared to other options are inconclusive. (3) Three studies compare the effectiveness of full CBAM and CBAM on imports only in protecting global welfare. Both policy designs enhance global welfare (relative to the no-CBAM scenario), but there are no consistent conclusions about the ranking of policy options.		
B. Sectoral coverage		~	~	**Comprehensive ≽ EITE** [56]
		The non-EITE sectors in certain economies could have non-negligible carbon footprints. Therefore, CBAM with comprehensive sectoral/industrial coverage could be more effective than CBAM with EITE-only coverage and enhance global welfare.		
C. Carbon Content Defaults	**C1. GHG coverage**	**All GHG ≽ Carbon dioxide** [58]	**All GHG ≽ Carbon dioxide** [58; 59]	**All GHG ≽ Carbon dioxide** [59]
		Broaden GHG coverage enhances CBAM's effectiveness in protecting competitiveness, reducing GHG leakage, and improving global welfare.		
	C2. System boundary	**Scope 1&2&3 ≽ Scope 1&2 ≽ Scope 1** [20; 28; 52; 56; 72; 77]	**Scope 1&2&3 ≽ Scope 1&2≽ Scope 1** [20; 50; 52; 56; 77]	**Scope 1&2&3 ≽ Scope 1&2 ≽ Scope 1** [20; 52; 56]
		Considering the full implicit emission improves the effect on the three objectives of CBAM. Yet, notably what not discussed here – but of major relevance in practice – is the feasibility and cost of tracking indirect emissions.		
	C3. Benchmark	**Foreign ≽ Domestic, Actual ≽ BAT,** [1; 15; 26; 27; 36; 48; 49; 56; 63; 77; 89]	**Foreign ≽ Domestic, Actual ≽ BAT,** [1; 26; 36; 48; 49; 56; 77; 89]	**Foreign actual ≽ Domestic actual** [56]
		Foreign actual ≽ Domestic avoided [15]		**Domestic actual ≽ Foreign actual** [35; 48; 49]
		Using a benchmark that approximates the true carbon content of tradables improves the effectiveness of CBAM on protecting competitiveness and reducing leakage. Yet, regarding global welfare, lower benchmark would reduce the burden on low- and middle-income economies and therefore enhance global welfare by reducing inequality.		
	C4. Level	**Hybrid ≽ Firm ≽ Sector** [20]	**Firm ≽ Hybrid ≽ Sector** [20]	**Firm ≽ Hybrid ≽ Sector** [20]
		Defaults of higher resolution (Firm level vs Sector level) enhances CBAM's effectiveness of reducing leakage and enhance global welfare. Yet this does not hold true for protecting competitiveness.		
D. Use of Revenues		**Importer ≽ Exporter** [55]	**Importer ≽ Exporter** [53]	
		Retaining CBAM revenues in the implementing coalition (importer) can better protect coalition's competitiveness and prevent carbon leakage		
E. Price level		~	**Full ≽ partial** [10]	**Partial ≽ Full** [10; 70]
		Adopting a CBAM price equal to that of the implementing region/coalition (FULL) better prevents carbon leakage. Yet, in terms of global welfare, a lower CBAM price can better protect low-income countries and thus enhance global welfare.		

Notes: This table summarizes quantitative evidence on the ranking of preferable policy design of CBAM on 3 objectives, namely, protecting competitiveness, reducing carbon leakage, and reducing global welfare costs, respectively. '≽' stands for weak preference. For example, 'Full ≽ Import' in terms of protecting competitiveness indicates that a full CBAM is preferable or at least similar to CBAM on import only on protecting competitiveness. Preferential ranking is concluded from quantitative *ex-ante* studies examining CBAM with alternative policy designs. Supporting studies are indexed by numbers (interested readers may refer to Tab. A3 in Appendix). Alternative policy designs are detailed below.

Coverage: *import*, *export* and *full* refer to import-only CBAM, export-only CBAM, and full CBAM, respectively.

System boundary: Scope 1, 2 and 3 refers to scope 1, 2 and 3 emissions.

Carbon Content Defaults: *foreign* and *domestic* refer to foreign and domestic data, respectively. *Actual*, *BTA* and *avoided* refer to actual emission rate, emission rate of Best Technology Available, and avoided emissions, respectively. Regarding defaults level, *hybrid*, *firm* and *sector* refer to hybrid, firm-level, and sector-level defaults.

Use of revenue: *importer* and *exporter* refer to whether importer (the implementing economy) or exporter obtain the revenues.

Price level: *full* and *partial* refers to using domestic carbon price and lower than domestic carbon price, respectively.

4.3.2. Scope of sector/product coverage

In terms of the sectors or products subject to CBAM (hereafter referred to as 'scope'), emissions-intensive-trade-exposed (EITE) industries, where the likelihood of carbon leakage is greatest, are usually of utmost concern. It is optional to impose CBAM on either all sectors/products or a narrower range of industries/products. Clearly, greater coverage expands the effect of CBAM (Böhringer et al., 2012b). Although the EITE sector often accounts for the majority carbon emissions, non-EITE sectors might also need to be taken seriously (Böhringer et al., 2014). Yet, the sector coverage is not an arbitrary choice. On account of WTO rules and fairness considerations, the coverage of CBAM adjustments cannot exceed that of domestic carbon pricing policies.

4.3.3. Determining carbon content

Accounting for the exact carbon content of a product is difficult, if not impossible, given that obtaining data from foreign manufacturers is costly. A solution is to use default emission rates (hereinafter referred to as 'defaults'). The design of the default computation requires reckoning with the following considerations.

First, a system boundary for emissions accounting must be determined. According to the Greenhouse Gas Protocol, carbon emissions can be divided into three different scopes (Michalek, 2016, p. 335). Scope 1 refers to direct emissions from owned or controlled sources such as those from fossil fuel combustion, company vehicles, and fugitive emissions. Scope 2 comprises indirect emissions embodied in the electricity, heat and steam consumed in production activities. Scope 3 covers the indirect carbon emissions embodied in the other products and services purchased by the producer; transportation and distribution; and waste disposal. The system boundaries mostly discussed to be covered in the CBAM are Scope 1 only; Scopes 1 and 2 only or Scopes 1, 2 and 3. The last type of system boundary is called the carbon footprint.

Broader system boundaries require more emissions data and are, therefore, often costlier. In terms of effectiveness, most studies agree that a broader system boundary usually contributes to greater competitiveness and anti-leakage impact at the macro level (Böhringer et al., 2012b, 2017, 2018; Burniaux et al., 2013). However, at the industry level, adopting broader system boundaries may lead to worse competitive outcomes for several particular industries (Fouré et al., 2016; Monjon & Quirion, 2011). In terms of reducing global welfare costs to achieve a climate goal, three studies support the theory that adopting wider system boundaries would help save more costs in implementing climate action.

Second, alternative benchmarks exist to compute a default rate. Two dimensions need to be considered here, one is whether to use foreign data or national data of the same product? Carbon intensity of the same products from developing countries is often higher than those produced by developed countries. Therefore, CBAM implemented by developed countries based on foreign emission rates usually means a higher burden for developing countries compared with using domestic emission rates and often stronger anti-leakage and competitiveness effects. As most of the existing studies are based on the perspective of developed countries, using foreign data implies therefore a heavier burden. However, using foreign data presents difficulties in data acquisition. The second difficulty is how to calculate the carbon content. Commonly discussed options are, for example, actual emission and best available technology (hereinafter referred to as foreign BAT). The former represents higher defaults and, therefore, better protection against carbon leakage and competitiveness. Another option is domestic avoided emissions, a term that refers to the emissions that would occur if all imports were produced domestically. As an attempt in this regard, Rocchi et al. (2018) presented a method for calculation. In terms of global welfare, three studies showed that using domestic actual emissions as a default results in a higher global welfare level than using foreign actual emissions (Antimiani et al., 2013; Dong et al., 2015; Mattoo et al., 2013). Conversely, Böhringer et al. (2017) reported that the global welfare of the EU appears higher when using foreign emission defaults compared to using domestic defaults.

Then, the level of defaults must be decided, for example, on products level, firm-level, sector-level, economy-wide, or a uniform one-for-all default can be applied. Similarly, a more specific default gives more incentives for firms to reduce emissions but increases the difficulties and costs of implementation. Böhringer et al. (2017) compared the economic effectiveness of using default at different levels and concluded that regardless of data generation costs, firm-level default maximizes global welfare as it incentivizes exporting firms to respond to CBAM. Also, hybrid default can also be used. For example, using firm-specific emissions for

Scope 1 and region-specific emissions for Scope 2 emissions, which provides insights on combining data only available at different levels (Böhringer et al., 2017).

4.3.4. Use of revenues

Typically, policymakers can consider obtaining and using CBAM revenues domestically, returning the revenues to the taxed country, or a mixed use – part retention and part return. Returning revenues might reduce the effectiveness of CBAM in combating leakage and preserving the competitiveness of the home country (Bednar-Friedl et al., 2012; Böhringer et al., 2012a). However, a partial refund of revenues to developing countries may help alleviate their concerns about CBAM (Michalek, 2016).

4.3.5. Adjustment price

The adjustment price for carbon is one of the key factors that affects the size of CBAM's impact. The magnitude of the relative price change of imports is what generates the competitiveness impact. For the implementing country, if a lower carbon price has the effect of preserving the country's competitiveness, then a higher price would amplify this effect (Zhong & Pei, 2022).[8] In this sense, implementing countries have the incentive to maximize their own benefits by setting higher CBAM prices (Balistreri et al., 2019). However, the CBAM price is not an arbitrary choice. For equity reasons, its cap cannot exceed the carbon price difference between the implementing and exporting countries. Most studies assumed a CBAM price equalling the differential between the carbon price of two countries to achieve the goal of levelling the playing field.

A related issue here is whether international differences in carbon prices can rationalize CBAM in terms of economic efficiency. From a global welfare perspective, setting the CBAM adjustment price equal to the difference in carbon prices between the two countries is not necessarily optimal. Eyland and Zaccour (2014) demonstrated through a game model that, to maximize global welfare, optimal CBAM price is lower than carbon difference. The interval of the best partial correction rate identified is [0:403; 0:486]; that is, the optimal carbon price is equal to the carbon price differences multiplied by the partial correction rate. Balistreri et al. (2019) found that at the point where the implementing country offsets the trade impact on the exporting country by refunding CBAM revenue – as this is a huge concern for CBAM implementation in the Global South – the utility of the implementing country exhibits an inverted U-shape in terms of price. The point of maximum utility for the implementing country occurs when the CBAM price is lower than half of the domestic carbon price. Therefore, in terms of global welfare, eliminating carbon price differences is not necessarily a first-best design of CBAM.

5. Conclusions

This study presents a systematic literature review of 97 relevant studies on CBAM between 2004 and August 31, 2021. This branch of literature has evolved from focusing on conceptualization and feasibility, to examining concrete implementation and policy design. Theoretically, it is postulated that CBAM is an effective tool to protect fair competition, prevent carbon leakage and limit global welfare cost. Yet, in practice, its effectiveness depends largely on policy design and characteristics of the implementing economy.

Our review shows that the effectiveness of CBAM in preventing carbon leakage largely depends on policy stringency. That is, the more carbon content covered by CBAM, the broader the product range, and the higher the CBAM price, the more effective it is in preventing carbon leakage. However, the positive correlation does not always hold true in terms of protecting domestic competitiveness or limiting global welfare cost. For example, CBAM on exports only can be more effective in protecting local competitiveness compared to full CBAM and CBAM only on import. Also, CBAM only on import could cause less global welfare loss compared to full CBAM (although opposite evidence also exists). Meanwhile, adopting domestic default carbon rates for import could enhance global welfare, as it helps to reduce the burden on low-income and developing countries (thus reducing global income inequality). Likewise, adopting a CBAM price that is lower than the carbon price differential may also improve global welfare.

[8]In contrast, for countries where CBAM exhibits a negative competitiveness effect, increasing the carbon price also amplifies it.

To summarize, there is no one-size-fits-all approach to design and implement CBAM to tackle issues such as competitiveness, carbon leakage or global welfare; policy design and characteristics of the economy implementing CBAM matter. An effective use of CBAM requires policymakers to tailor-make appropriate policy design to match location specific economic characteristics and implementation conditions. As a first step, the present review tentatively provides evidence-based guidance for policymaking by synthesizing plausible outcomes of alternative policy designs concerning the effectiveness of CBAM.

Finally, we would like to highlight two remaining challenges for further research. For instance, the EU's recent introduction of CBAM is generating controversy globally, largely because the issue of its fairness is unresolved. The CBAM is envisioned by the implementing developed countries as a means to safeguard fair competition, but developing countries believe that fair competition measured by equal emission costs is inherently unfair. Developing countries would argue that developed countries should bear more of the mitigation burden than developing countries, either with respect to their historical responsibilities or current capabilities. In fact, the controversy reflects a global disagreement over the distribution of mitigation responsibility, an issue that is a long-standing source of disagreement in climate negotiations. Without consensus on the allocation of responsibilities, the fairness of any resource or transfer of burden between countries cannot be discerned. This is the dilemma of the CBAM fairness controversy. How revenues can be used to reduce income inequality, or help developing countries mitigate emissions, is critical to moderating the CBAM controversy. Several studies have begun to address the fairness issue; however, more effort and ideas are called for to resolve it and allow the use of the CBAM to advance.

Another important issue is the compatibility of CBAM with the international climate policy architecture. The CBAM was initially envisioned as a levy on non-members of climate clubs that implemented a uniform carbon price, proposed as a penalty or an incentive to join the club. However, the current international climate policy architecture, under the Paris Agreement, is not based on a price-based approach of coordination. Rather, it is a quantity-based approach of responsibility allocation, with concepts such as Nationally Determined Contributions (NDCs) guiding this. In this context, the emergence of different carbon prices across countries should be acceptable under the current climate policy architecture. In this case, where there are different carbon prices across countries, it is questionable to use the price difference as the reference point or basis for the CBAM. Whether the CBAM can address its incompatibility with the current climate policy architecture via policy design is also a question worth exploring.

Acknowledgements

We thank four anonymous reviewers and the Editor, and participants at various seminars for their suggestions and encouragement. Remaining errors are our own.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The research was supported by the National Natural Science Foundation of China (no. 72273149; 41675139) and China Scholarship Council (no. 201808080249).

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