Welfare-optimal policy response to border carbon adjustments: An emerging economy perspective*

Simon J. Bolz†
TU Dresden

Johannes Gallé‡
PIK Potsdam

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Abstract

From the perspective of an emerging economy, this paper develops a Melitz-style model of asymmetric countries to investigate optimal environmental policy responses to a Border Carbon Adjustment (BCA) imposed by a trading partner. By analytically examining the impact of a unilateral emissions tax rise on endogenous productivity cut-offs, we show that the presence of a BCA reverses the policy's effect on the trading partner's export threshold, thereby allowing for more imports. This mitigates the welfare losses typically associated with unilaterally increasing environmental stringency. The model is calibrated using detailed Indian firm-level data on emissions, productivity, and export performance. We estimate that the relative welfare loss of raising Indian carbon pricing to the level of the European Union (EU) is around 50% lower as compared to a scenario without a BCA. When additionally accounting for environmental disutility, the analysis shows that the existence of a BCA increases India's welfare-optimal emissions tax under low and moderate social cost of carbon (SCC) scenarios. In contrast, the presence of a BCA can reduce the welfare-optimal tax in settings of very high SCCs.

JEL codes: F18, H23, Q56, Q58
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†Technische Universität Dresden, Faculty of Business and Economics, Helmholtzstraße 10, 01069 Dresden, Germany; Email: simon.bolz@tu-dresden.de.

‡Potsdam Institute for Climate Impact Research, EUREF Campus 19, 10829 Berlin Germany; Email: jgalle@pik-potsdam.de.

1 Introduction

Carbon pricing, as a form of environmental regulation, is a fundamental tool for reducing carbon emissions and mitigating global warming. Yet, as long as substantial differences in carbon pricing across countries exist, there is a possibility of pollution outsourcing to less stringent environmental regimes (Copeland and Taylor, 2003; Cherniwchan et al., 2017; Levinson, 2023). The leakage of carbon emissions across countries provides a major obstacle to the effectiveness of environmental policy measures. Given the possibility of large firms to relocate production abroad, unilateral or poorly designed multilateral policy reforms can lead to the relocation of emissions towards weekly regulated destinations (Aichele and Felbermayr, 2015).[1] Against this background, Border Carbon Adjustments (BCAs) are discussed as a complementary trade policy designed to augment domestic carbon pricing schemes and to mitigate carbon leakage. In particular, the European Union is the first market to introduce a BCA, the so-called Carbon Border Adjustment Mechanism (CBAM) as a key pillar in its future EU trade policy.[2] Coming into effect by 2026, the EU-CBAM complements the European Emission Trading Scheme (EU-ETS) and aims to ensure competitiveness of the most emission-intensive industries as well as to preventing leakage of carbon emissions and particularly the relocation of carbon-intensive production.[3]

While BCAs aim to prevent the relocation of emissions and production, there is a concern that they could inadvertently shift income from the Global South to the Global North. (Larch and Wanner, 2017).[4] This connects to the debate around environmental and climate justice, raising the question how low- and middle-income countries (LMIC) facing a BCA can optimally respond. Our analysis focuses on carbon pricing as a domestic policy choice for BCA exposed countries and thereby influencing the effective carbon tariff faced by exporters. While previous literature has primarily focused on the importing country perspective (e.g. the EU) (Brunel and Levinson, 2024), the goal of this paper is to identify whether and to what extent a country affected by a BCA (e.g. India) can benefit from raising its emission tax to the level of the trading partner that sets the adjustment mechanism. This is closely connected to the question whether a

[1] We acknowledge that empirical evidence on emissions leakage is mixed and strongly depends on the respective policy setting (Dechezleprêtre et al., 2022).

[2] We acknowledge the use of both terms, Border Carbon Adjustment (BCA) and Carbon Border Adjustment Mechanism (CBAM), in the context of carbon tariffs. While CBAM typically refers to specific policy proposals, such as the European Union's mechanism, BCA is a more general term encompassing a broader range of carbon tariff policies. In this paper, we primarily use the term BCA due to its wider applicability.

[3] Similar measures have been discussed in other countries such as Canada, Japan and the United States (Brunel and Levinson, 2024), where the United Kingdom has announced to implement an UK CBAM.

[4] In fact, the European Union has acknowledged that its measures could potentially have disproportionate adverse impacts on low- and middle-income countries (European Commission, 2021).

BCA can be effective in incentivizing a less stringent trading partner to tighten its environmental policy. Moreover, it is important to identify key factors that drive welfare changes in country exposed to a BCA. To this end, we build on an environmental Melitz model of two countries with heterogeneous firms à la Felbermayr et al. (2013), allowing for structural asymmetries between trading partners. As the productivity distribution of firms in low- and middle-income countries is much more skewed on thereby fundamentally differs from high income countries (e.g. Hsieh and Klenow, 2009; Li and Rama, 2015; Restuccia and Rogerson, 2017), the incorporation of asymmetric firm heterogeneity within a Melitz framework allows for a nuanced assessment from an emerging economy perspective. We calibrate the model to the setting of India as an emerging exporting market, using detailed Indian firm-level data containing information on fuel consumption, productivity and exports.

At an analytical level, we find that the introduction of a Border Carbon Adjustment (BCA) by the trading partner fundamentally alters the effects on endogenous productivity cut-offs. Specifically, the BCA reverses the impact on the trading partner's export cut-off, thereby enabling a greater variety of traded goods. This mechanism significantly reduces the welfare losses typically associated with a unilateral carbon tax increase, even without accounting for environmental disutility.

For the entire Indian manufacturing sector, our numerical simulations highlight the quantitative relevance of this mechanism. In the absence of a BCA, raising India's carbon price to the level of the EU results in a welfare reduction of 2.75%. In contrast, when a BCA is in place, the relative reduction in welfare falls to 1.31%, mitigating the relative welfare loss by around 52%. A set of more granular sector-level simulation exercises reveals that the relative attractiveness of raising the emission tax is particularly strong in sectors with a high energy intensity and a large degree of trade openness, such as steel and cement. Furthermore, we show that reducing firm heterogeneity -induced by a more dense productivity distribution of firms- leads to an overestimation of the welfare smoothing effects, underscoring the importance of explicitly accounting for firm heterogeneity for welfare outcomes. Incorporating firm heterogeneity constitutes an important facet of environmental policy analysis. It can be motivated by strong empirical evidence for a negative link between firm productivity and emissions intensity (e.g. Sogalla, 2025). In the context of the effect of unilateral carbon pricing on the economy, this relationship has further implications: A carbon tax rise drives out the least productive (most emissions-intensive firms) in the economy, raising average productivity – and lowering average emissions intensity levels – across all active firms (Egger et al., 2021). Apart from within-changes in input mix, this constitutes an important additional channel through which environmental policy affects overall environmental performance. We further incorporate additional dimensions of structural heterogeneity across countries. We find that, in the presence of a BCA, welfare reductions - resulting from an unilateral carbon tax increase - are more pronounced in smaller and less productive economies relative to the trading partner.

Finally, we extend our framework to incorporate environmental disutility from global carbon emissions. Accounting for environmental damage introduces an inverted U-shaped relationship between a country's emissions tax and its welfare, giving rise to a welfare-optimal emissions tax. For the case of India, we show that the presence of a BCA introduces an additional welfare-enhancing channel. This results in a higher welfare-optimal emissions tax under low and moderate social cost of carbon (SCC) scenarios. Furthermore, we identify a range of SCC levels for which adopting the trading partner's carbon tax rate becomes welfare-optimal for India. However, under very high SCC scenarios, the presence of a BCA can lead to a lower welfare-optimal carbon tax as compared to a scenario without BCA. In such cases, moving towards tax rates above the trading partner's (EU) level does not produce additional tariff reductions, thus increasing the net marginal disutility associated to enhanced environmental stringency.

Our analysis contributes to various strands of the literature. We build on a literature around Kreickemeier and Richter (2014), Forslid et al. (2018) and LaPlue (2019) that extend heterogeneous firm models of Melitz (2003) by emission generation and abatement as in Copeland and Taylor (1994).These models focus on the environmental effect of trade liberalization across symmetric countries and do not investigate the role of environmental policy. As in Felbermayr et al. (2013), the heterogeneous-firm model in our setting allows for structural asymmetries between countries. Within a setting of heterogeneous firms and their exporting behavior, our contribution is closely linked to Egger et al. (2021) who analyze the environmental effects of a unilateral emisison tax increase in absence of a BCA.

We add to the growing body of research on the effectiveness of border carbon adjustments (BCAs). Computable general equilibrium (CGE) models generally find that BCAs significantly reduce emissions leakage (Elliott et al., 2010; Fischer and Fox, 2012; Böhringer et al., 2012a,b; Schenker et al., 2018; Beaufils et al., 2024), although some studies suggest more moderate impacts (Babiker and Rutherford, 2005; Böhringer et al., 2022). Structural gravity models similarly associate carbon tariffs with substantial mitigation of leakage but highlight potentially significant welfare costs (cf. Larch and Wanner, 2017).[5]

[5] Ambec et al. (2024), using a two-country model with heterogeneous abatement costs, find that BCAs can reduce leakage but may also distort global competition.

Recent studies employing multi-sector trade models with firm heterogeneity reveal additional channels through which BCAs operate. Farrokhi and Lashkaripour (2025) show that even optimally designed border taxes offer only limited potential for global emissions reduction as border tariffs could drive down global energy prices and fail to target non-traded production. Artuc and Sommer (2024) emphasize that BCAs which exclude emissions from the upstream value chain can trigger downstream leakage through production outsourcing.

Quantitative models that account for heterogeneous firm-level sourcing decisions (Coster et al., 2024; Stillger, 2025), as well as those incorporating both productivity heterogeneity and input-output linkages (Sogalla, 2025), suggest that the effectiveness of the EU-CBAM may be limited by firms' ability to adapt their supply chains. Focusing on France, Coster et al. (2024) link CBAM-induced leakage reductions to losses in domestic welfare.

Beyond the analysis of effectiveness in terms of carbon leakage, our contribution emphasizes the welfare costs associated with heightened environmental stringency under a BCA, with a particular focus on the Global South perspective. Specifically, we seek to identify the welfare-related incentives that push relatively unregulated emerging economies to adopt or strengthen national carbon pricing in response to a BCA implemented by a trading partner in the Global North. Key to this question is a comparison of welfare costs induced by unilaterally increased environmental stringency.

One of the few contributions assessing CBAM-induced welfare implications across (regulated and unregulated) countries is Clausing et al. (2025). Employing a quantitative equilibrium model with plant-level data for the aluminum and steel sector, they find that BCAs effectively mitigate emissions leakage without imposing disproportionate burdens on lower-income countries. However, this outcome is conditional on the finding that production in developing countries is not structurally more emissions-intensive compared to that in higher-income economies.

However, there is evidence of systematic differences in productivity levels between low-income and high-income countries, which may lead to variations in carbon input intensities per unit of output (Hsieh and Klenow, 2009, 2014; Li and Rama, 2015; Akcigit et al., 2021; Restuccia and Rogerson, 2017; Nataraj, 2011). This provides a strong rationale for investigating welfare effects in the Global South using a Melitz-style model combined with abatement technology as in Copeland and Taylor (1994), where productivity differences are explicitly linked to variations in emissions intensity.

The rest of the paper is structured as follows: Section 2 outlines the model. Section 3 adds a comparative static analysis around the impacts on productivity cut-offs and welfare in the context of a unilateral emissions tax increase in the presence of a BCA. Section 4 describes the data generation as well as model calibration. In Section 5, a quantitative analysis for the effect of emission tax changes on welfare is provided. Section 6 concludes.

2 Model

2.1 Model Setup

Within the framework of Melitz (2003), we allow for wage endogeneity and country asymmetry as in Felbermayr et al. (2013) and extend the production technology to the use of emissions, thereby following Egger et al. (2021). Following Dixit and Stiglitz (1977), consumer preferences are a CES aggregate over varieties of a differentiated good:

$$U_i = \left(\int_{\omega \in \Omega_i} q[\omega]^{\rho} d\omega \right)^{1/\rho}, \text{with } \sigma = 1/(1-\rho) > 1. \tag{1}$$

where i stands for country i. With aggregate expenditure $R_i = Q * P$ and $P = \left[\int_{\omega \in O} p(\omega)^{1-\sigma} d\omega \right]^{\frac{1}{1-\sigma}}$, utility maximization yields demand per variety in country i:

$$q[\omega] = R_i P_i^{\sigma-1} p[\omega]^{-\sigma}. \tag{2}$$

In a setup of monopolistic competition, there is a continuum of heterogeneous firms that differ in productivity φ. Firms have the possibility to use labour l in production as well as for emissions abatement. As emissions are priced with an emissions tax $t_i > 0$, abatement activity lowers a firm's emission tax bill. Hence, each firm allocates an (endogenous) share of labor $\xi \in (0;1)$ for production and $1-\xi$ for emissions abatement, defining firm-level production as $y(\varphi) = \varphi \xi(\varphi) l(\varphi)$. As in Copeland and Taylor (1994), the emissions-generating process is defined as

$$e(\varphi) = [\xi(\varphi)]^{\frac{1}{1-\alpha}} l(\varphi), \tag{3}$$

with ξ as the endogenous share of labor allotted to emission-intensive production and $\alpha \in (0;1)$ as the exogenous cost share of labor allotted to emission abatement. Hence, a high α denotes a low cost weight of emissions in the production process. Inserting (3) into the firm's production technology yields a Cobb-Douglas production function consisting of labor and emissions as inputs:

$$y(\varphi) = \varphi[l(\varphi)]^{\alpha}[e(\varphi)]^{1-\alpha}. \tag{4}$$

Each firm in country i draws its productivity level from a pareto distribution $G_i[\varphi] = 1 - (b_i/\varphi)^k$ with $k > 2$ as shape parameter and b_i as the lower bound of the productivity distribution in country i. Firms in country i learn about their productivity level after paying fixed entry costs $w_i\, f^e$. Domestic market access is connected to fixed costs $w_i\, f^{ii}$ while exporting to country j is associated to additional fixed costs $w_i\, f^{ij}$.[6] Firms in country i and j both have the possibility to export to the other country if their export revenue covers the fixed costs associated to exporting. For exporting, both firms face iceberg transport costs $\tau > 1$. Additionally, country j imposes a BCA $\gamma_{ji} = Min[1, (t_j - t_i) * (1 - \alpha) + 1]$ on imports from country i. Hence, country j's import tariff depends on the asymmetry in environmental stringency between the two countries. We assume that country j follows a higher environmental stringency in the baseline scenario, i.e. $t_j > t_i$. The BCA sets the international emission tax difference as tariff, while considering the sectoral emission weight $(1 - \alpha)$. The mechanism also ensures that γ_{ji} does not fall below a value of 1, even if $t_i > t_j$. At the same time, country i may impose a fixed ad-valorem tariff rate $\gamma_{ij} \geq 1$ on imports from country j.

Cost minimization and mark-up pricing allow to derive the following pricing functions for non-exporting and exporting firms of country i:

$$p_{ii} = \frac{\beta w_i^{\alpha} t_i^{1-\alpha}}{\rho\varphi}, \tag{5}$$

$$p_{ij} = \frac{\tau\gamma_{ji}\, \beta w_i^{\alpha} t_i^{1-\alpha}}{\rho\varphi}, \tag{6}$$

where $\beta \equiv (1-\alpha)^{(\alpha-1)}\alpha^{-\alpha}$ is a constant. Note that the country-wide wage rate w_i is determined endogenously in general equilibrium, while the country-specific emission tax t_i is an exogenous parameter set by the policy maker.

This yields the following zero-profit cut-off conditions (ZCP) for firms in i from entering market i (domestic sale) and entering market j (exporting):

[6] For country j, firm production and firm entry is derived in the same fashion as for country i.

$$R_i P_i^{\sigma-1}\left(\frac{\rho\varphi_{ii}^*}{\beta w_i^\alpha t_i^{1-\alpha}}\right)^{\sigma-1} = \sigma w_i f_{ii}, \tag{7}$$

$$R_j P_j^{\sigma-1}\gamma_{ji}^{-\sigma}\left(\frac{\rho\varphi_{ij}^*}{\tau\beta w_i^\alpha t_i^{1-\alpha}}\right)^{\sigma-1} = \sigma w_i f_{ij}. \tag{8}$$

Cut-off conditions for firms in j from domestic sales and exporting hold analogously.

Following Felbermayr et al. (2013), we derive the price index in country i as:

$$P_i^{1-\sigma} = \theta\left[M_i\left(\frac{\rho\varphi_{ii}^*}{\beta w_i^\alpha t_i^{1-\alpha}}\right)^{\sigma-1} + m_{ji}M_j\left(\frac{\rho\varphi_{ji}^*}{\tau\gamma_{ij}\,\beta w_j^\alpha t_j^{1-\alpha}}\right)^{\sigma-1}\right], \tag{9}$$

where $\theta = k/(k-\sigma+1)$ is a constant and $m_{ji} \equiv \left(1 - G\left[\varphi_{ji}^*\right]\right) / \left(1 - G\left[\varphi_{jj}^*\right]\right) = \left(\varphi_{jj}^*/\varphi_{ji}^*\right)^k$ is the endogenous share of exporters from country j.

The free entry conditions (FE) for country i and j demand that expected value of entering equals fixed costs of entering. These are derived as:

$$\frac{\sigma-1}{k-\sigma+1}(\varphi_{ii}^*)^{-k}\,\left[f_{ii} + m_{ij}\,f_{ij}\right] = f_i^e\,b_i^{-k}, \tag{10}$$

$$\frac{\sigma-1}{k-\sigma+1}(\varphi_{jj}^*)^{-k}\,\left[f_{jj} + m_{ji}\,f_{ji}\right] = f_j^e\,b_j^{-k}. \tag{11}$$

Using the labour market clearing condition, the mass of firms in country i and j can be derived as:

$$M_i = \frac{b_i^k L_i(\sigma-1)}{(1+\alpha(\sigma-1))\,k\,f_i^e}(\varphi_{ii}^*)^{-k}, \tag{12}$$

$$M_j = \frac{b_j^k L_j(\sigma-1)}{(1+\alpha(\sigma-1))\,k\,f_j^e}(\varphi_{jj}^*)^{-k}. \tag{13}$$

As in Felbermayr et al. (2013), assuming that $f_{ii} = f_{jj} = f_d$, $f_{ij} = f_{ji} = f_x$ and $f_i^e = f_j^e = f^e$ as well as making use of the balanced budget condition $w_i b_i^k L_i(\varphi_{ij}^*)^{-k} = w_j b_j^k L_j(\varphi_{ji}^*)^{-k}$ allows to express aggregate expenditure R (the sum of expenditure on domestic and foreign varieties) in country i and j as:

$$R_i = M_i\bar{r}_{ii} + \gamma_{ij}M_j\bar{r}_{ji} = \sigma\theta M_i w_i\left[f_d + \gamma_{ij}m_{ij}f_x\right], \tag{14}$$

$$R_j = M_j\bar{r}_{jj} + \gamma_{ji}M_j\bar{r}_{ij} = \sigma\theta M_j w_j\left[f_d + \gamma_{ji}m_{ji}f_x\right]. \tag{15}$$

where $\bar{r}_{ji}$ denotes average sales of an exporting firm from country j to i. At the same time, aggregate revenue V in each country is defined as the sum of worker income, income from BCA or ad-valorem tariff as well as income from domestic emission taxation. The latter two are redistributed to all individuals L in a lump-sum fashion:

$$V_i = w_i L_i + (\gamma_{ij} - 1) M_j \bar{r}_{ji} + t_i E_i, \tag{16}$$

$$V_j = w_j L_j + (\gamma_{ji} - 1) M_i \bar{r}_{ij} + t_j E_j. \tag{17}$$

With a balanced budget, $R = V$ has to hold in each country. Note that the mass of Labor L_i and L_j in each country is exogenously given, while the mass of Emissions in country i and j, following Egger et al. (2021) can be derived in a similar fashion as the mass of firms M:

$$E_i = (1-\alpha) b_i^{-k} \frac{L_i(\sigma-1)}{1+\alpha(\sigma-1)} \frac{w_i}{t_i}, \tag{18}$$

$$E_j = (1-\alpha) b_j^{-k} \frac{L_j(\sigma-1)}{1+\alpha(\sigma-1)} \frac{w_j}{t_j}. \tag{19}$$

Consequently, the model is based on six endogenous variables, namely φ_{ii}^*, φ_{jj}^*, φ_{ij}^*, φ_{ji}^*, as well as the wage rates w_i and w_j. The endogenous variables can be determined in levels using the four ZPCs as well as the two Balanced Budget Conditions. As choice of numéraire, we set the foreign wage w_j equal to one.

3 Comparative Statics

3.1 Effect of Unilateral Emissions Tax Reform on Cut-Offs

In the following, we want to show analytically how enhanced environmental stringency in country i (thereby reducing the structural policy asymmetry $t_j > t_i$) affects model parameters and welfare in the reforming country i.

The four productivity cut-offs φ_{ii}^*, φ_{jj}^*, φ_{ij}^*, φ_{ji}^* are the key endogenous variables driving effects on various variables of outcome. Hence, it is vital to understand how an emissison tax increase in country i influences these cut-offs. In this subsection, we analyze how an increase in country i's emissions tax ($dt_i > 0$) affects productivity cut-offs of both countries (i and j) under two regimes: (i) in absence of a BCA, i.e. with add-valorem tariffs $\gamma_{ij} = \gamma_{ji} > 1$[7] and (ii) in presence of a BCA imposed by country i, i.e. with country j's tariff representing a carbon

[7] While regime (i) is counterfactual to the setting outlined in Section 2, it is useful to clearly isolate the impact the BCA imposed by country j, as outlined in regime (ii).

tariff, $\gamma_{ji} = Min[1, (t_j - t_i) * (1 - \alpha) + 1] \geq 1$. As common in Melitz-extensions with country asymmetries, we employ log-linearization in order to derive percentage changes in response to a percentage increase in country i's emission stax t_i.

Without BCA - regime (i). In the absence of a BCA, we can completely build on the analytical results of Egger et al. (2021) in the context of a unilateral environmental policy reform. We first inspect the effect on country i's export cut-off φ^*_{ij}. The percentage change shows to be clearly negative, i.e.

$$\frac{\hat{\varphi^*_{ij}}}{\hat{t_i}} < 0, \tag{20}$$

indicating that the country's increased emissions lower the exporting threshold, incentivizing additional (relatively less productive) firms to enter the market of country j, as country i's market size shrinks relative to j due to the cost shock affecting producers of country i. In contrast, the domestic cut-off φ^*_{ii} increases:

$$\frac{\hat{\varphi^*_{ii}}}{\hat{t_i}} > 0, \tag{21}$$

reflecting the impact of the cost shock, forcing the least productive firms of country i to exit. Thus, following the Melitz-style mechanism average productivity across all active firms in country i increases.

At the same, the export cut-off in country j rises:

$$\frac{\hat{\varphi^*_{ji}}}{\hat{t_i}} > 0, \tag{22}$$

reducing the share of firms in country j that export to country i, owing to the reduced market size of country i.

With BCA - regime (ii). In presence of a BCA imposed by country j, the comparative static implications of enhanced environmental stringency in country i ($dt_i > 0$) change. The introduction of a carbon tariff by country j adds an additional channel to the overall effect of country i's emissions tax rise: While increased environmental stringency continues to act as a cost shock in country i, it also dampens the carbon tariff by country j as long as $t_i < t_j$ holds. This channel adds to the increased attractiveness of exporting from i to j, reinforcing the reduction in φ^*_{ij}:

$$\frac{\hat{\varphi^*_{ij}}}{\hat{t}_i} < 0. \tag{23}$$

While the domestic cut-off φ^*_{ii} increases more strongly in this scenario, the presence of the BCA reverses the effect on country j's export cut-off:

$$\frac{\hat{\varphi^*_{ji}}}{\hat{t}_i} < 0, \tag{24}$$

with the share of exporters rising in response to the rise in t_i in presence of the carbon tariff. The intuition for this outcome is as follows: The cost-shock induced by the policy reform in country i (decreasing its market size relative to country j) continues to exert upward pressure on the export cut-off in country j. However, the introduction of the BCA adds a counter-acting channel. As stated above, the presence of the BCA further raises the increase in exports from country i to j induced by the unilateral reform in country i. As country j consumes more imports from country i, it has to export more to country i in order to ensure for its trade balance and budget condition to hold. We can show that for any range $t_j > t_i$, this counter-acting effect outweighs the former channel, leading to a net decrease in country j's export cut-off φ_{ji}. Overall, the presence of the BCA amplifies the export-increasing effect of the unilateral emissions tax reform while reversing spillover effects on the trading partner. These findings are summarized in the Proposition below:

Proposition 1. *In comparison to a scenario without a border tariff, a unilateral emissions tax increase by country i in conjunction with a BCA imposed by country j:*

1. *lowers the export productivity cut-off in country i more strongly, resulting into a higher share of exporting firms in country i,*
2. *raises the domestic productivity cut-off in country i more strongly, resulting into fewer active firms in country i,*
3. *flips the effect on the export productivity cut-off in country j upside down, resulting into a higher share of exporting firms in country j.*

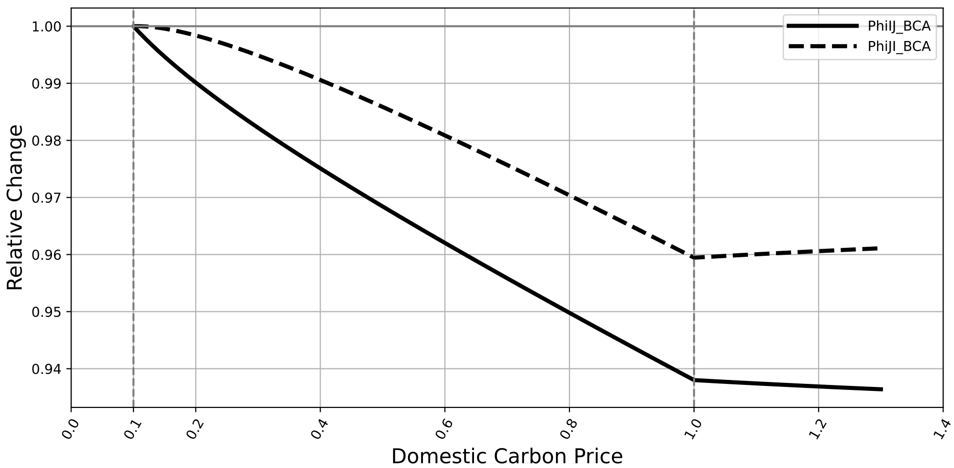
Proof. See Appendix A.1 and Appendix A.2 for details as well as Appendix A.3 for a proof on $(\hat{\varphi^*_{ji}}/\hat{t}_i) < 0$ in the presence of a BCA. □

3.2 Effect on Cut-Offs: Numerical Illustration

Complementing the formal analysis in the previous subsection, we now illustrate the effects of the policy reform in country i for both scenarios, i.e. with and without a BCA imposed by country j. For the baseline scenario in this numerical illustration, $t_j > t_i$ holds while we set $t_j = 1.0$ and $t_i = 0.10$.[8]

The following plots display the relative change of the unilateral environmental policy reform on country j's export cut-off, being the most central variable of outcome, with each of the baseline values normalized to one. Importantly, as the comparison of both plots reveals, the effect of country i's policy reform on these productivity thresholds strongly depends on whether (or not) the country implementing the environmental policy reform faces a BCA.

Figure 1: Effect of unilateral emission tax rise on export productivity cut-off



Notes: This plot uses parameter values for the aggregated manufacturing sector, displayed as "all" in Table 1. Remaining parameters are kept constant at $t_j = 1.0$, $\gamma_{ij} = 1.0$, $\tau = 1.1$, $b_i = b_j = 1.0$, $f_e = 2.5$, $L_i = L_j = 20$ and $w_j = 1$.

As outlined above, in the presence of the BCA (panel b), the effect on country j's export cut-off φ^*_{ji} profoundly differs from the scenario depicted in (panel a): As country i raises its emission tax and narrows the across-country gap in environmental stringency, it "melts down" the carbon tariff imposed by country j, allowing it to export more to country j, lowering its export cut-off more strongly. At the same time, as seen in Figure **??** the presence of the BCA flips the sign of the effect on country j's export cut-off upside down, inducing the cut-off to fall until t_i reaches parity with t_j. Once $t_i = t_j$, the BCA comes out of effect, re-establishing a negative marginal effect of the unilateral emisisons tax increase of country i. Thus, the presence

[8] As the emissions tax is not ad-valorem, any value of $t > 0$ imply positive emissions pricing.

of the BCA crucially impacts how a unilateral reform influences export thresholds (and thereby, trade volumes) across both countries.

3.3 Welfare Effects of Unilateral Carbon Pricing in Country i

Building on the insights highlighted above, we now extend our comparative static analysis to welfare. Borrowing from Felbermayr et al. (2013), we define country i's welfare as aggregate utility derived from consumption of both domestically produced (first summand) and imported (second summand) varieties:

$$W_i = U_i^{\rho} = \theta(\sigma - 1)^{\rho} \left[M_i (f_d \varphi_{ii}^*)^{\rho} + m_{ji} M_j \left(\frac{f_x}{\tau} \varphi_{ji}^* \right)^{\rho} \right], \tag{25}$$

where both domestically produced and imported varieties depend on cut-off productivities φ_{ii}^* and φ_{ji}^* as well as on the mass of firms in countries i and exporting firms from country j.

Applying a first-order log-linearization of W_i with respect to the policy change $dt_i > 0$, the proportional change in welfare can be written as:

$$\hat{W}_i = (k - \rho) \left[\tilde{\delta}_i (\hat{\varphi}_{ji}^* - \hat{\varphi}_{ii}^*) - \hat{\varphi}_{ji}^* \right], \tag{26}$$

where $\hat{W}_i \equiv \frac{dW_i}{W_i}$ denotes the log change in welfare, and $\tilde{\delta}_i \in (0, 1)$ is a weighting term denoting the initial expenditure share on domestic varieties. Recall that parameter $k > 1$ is the shape parameter of the Pareto distribution and as common in the literature, we additionally assume that $k > \rho$ holds throughout the analysis. This expression makes explicit that the welfare effect solely depends on the relative changes in the cut-offs for domestic and imported varieties, as well as on the initial composition of consumption in country i.

In the benchmark scenario where country j imposes a standard ad-valorem tariff, a unilateral carbon price increase in country i raises both φ_{ii}^* and φ_{ji}^* (i.e., $\hat{\varphi}_{ii}^* > 0$ and $\hat{\varphi}_{ji}^* > 0$).

Substituting these signs into the welfare expression Eq. (26), it is clear that welfare unambiguously decreases, since both terms inside the squared brackets are negative for any $\tilde{\delta}_i \in (0, 1)$. Thus, in the absence of BCA, a unilateral carbon price reform leads to a welfare loss in country i regardless of its initial domestic consumption structure.

Under a BCA imposed by country j, the emissions tax asymmetry is neutralized at the border. In this setting, a unilateral increase in t_i leads to a stronger increase in the domestic cut-off φ_{ii}^* but to a decrease in the import cut-off φ_{ji}^*, i.e., $\hat{\varphi}_{ii}^* > 0$ and $\hat{\varphi}_{ji}^* < 0$ (See Proposition 1).

Substituting these signs into the welfare change expression in Eq. (26) points to an ambiguous sign, since now the two terms in the squared bracket have opposite signs. The first term is negative (since $\hat{\varphi}^*_{ji} - \hat{\varphi}^*_{ii} < 0$), while the second term is positive (because $-\hat{\varphi}^*_{ji} > 0$). The overall welfare effect thus depends on the relative magnitudes of the changes and the size of $\tilde{\delta}_i$.

To better understand the mechanics, we examine two polar cases:

Case 1: $\tilde{\delta}_i \to 0$ (Only Imported Varieties). In this limit, country i consumes only imported varieties. The welfare change simplifies to $\hat{W}_i = (k - \rho)(-\hat{\varphi}^*_{ji})$.

Since $\hat{\varphi}^*_{ji} < 0$ under BCA, it follows that $\hat{W}_i > 0$. That is, an increase in country i's carbon price raises welfare by expanding access to imported varieties, thanks to improved terms of trade and increased (imported) consumption due to a dampened border tariff.

Case 2: $\tilde{\delta}_i \to 1$ (Only Domestic Varieties). In the opposite limit, where only domestic varieties are consumed, we have $\hat{W}_i = (k - \rho)(\hat{\varphi}^*_{ji} - \hat{\varphi}^*_{ii})$.

Here, since $\hat{\varphi}^*_{ji} < 0$ and $\hat{\varphi}^*_{ii} > 0$, the expression is negative: $\hat{W}_i < 0$. Welfare declines because fewer domestic varieties are available, and there are no gains from increased imports.

In realistic settings, empirical estimates suggest that the domestic expenditure share $\tilde{\delta}_i$ typically lies in the range 0.6 to 0.9 (Arkolakis et al., 2021). For this intermediate range, the overall welfare effect under a BCA remains negative, but the magnitude of the welfare loss is significantly attenuated compared to the case in absence of a BCA (regime (i) with ad-valorem tariff).

Therefore, while increased unilateral carbon pricing reduces welfare in country i in both scenarios, the presence of a border carbon tariff moderates the loss by improving access to imported varieties. This reinforces the view that border carbon adjustments can play an important role in containing competitiveness and welfare effects from unilateral climate policy.

Proposition 2. *A unilateral emissions tax increase by country i in conjunction with a BCA imposed by country j*

1. *induces a welfare gain for country i if the country's consumption varieties are exclusively or overwhelmingly imported (Case 1, $\tilde{\delta}_i \to 0$).*

2. *induces a welfare loss for country i if the country's consumption varieties are exclusively or overwhelmingly produced and sold domestically (Case 2, $\tilde{\delta}_i \to 1$)*

Proof. See above. □

As a consequence, for most empirically realistic scenarios $\tilde{\delta}_i \in (0.6, 0.9)$, the presence of the BCA significantly dampens the welfare losses associated to the unilateral environmental reform, as compared to a scenario without a border tax by country j. The extent to which the presence of the BCA mitigates the welfare loss for Indian manufacturing sectors will be illustrated in the following section.

4 Data

4.1 Data generation

Motivated by the introduction of the EU-CBAM, we are particularly interested in the welfare implications of a domestic policy response options from an emerging economy perspective. To this end, we calibrate the home country in the model with detailed Indian firm-level data representing an emerging export market. Except for carbon pricing, in the baseline scenario, all parameters of the foreign country (j, the EU) are set at the level of India (i). In subsection 5.4, we then allow for additional structural across-country heterogeneity, such as size and average productivity. For calibrating the home country, we rely on the Prowess database compiled by the Centre for Monitoring of the Indian Economy (CMIE). Prowess contains detailed information on about 50,000 Indian firms, covering more than 70% of national industrial output from the organized sector, and it is widely used in empirical work (e.g. Goldberg et al., 2010; De Loecker et al., 2016; Stiebale and Vencappa, 2018). The prowess data is based on annual financial statements of registered companies in India and contains detailed information on inputs and outputs. Importantly, firms are required to report their annual fuel consumption. We follow Barrows and Ollivier (2018) and assign each reported fuel (e.g. coal) default emission factors. Thereby, we are able to calculate total emissions for each firm. Overall, we use the data in order to calculate firm-level emission intensity, productivity and further obtain information on sales and exporting behavior. As a second data source, we rely on the World Input-Output Database (WIOD), where we obtain information on bilateral trade flows.

4.2 Calibration

In our calibration, we focus on the manufacturing sector. In our baseline version, we calibrate our model based on the entire manufacturing sector. We complement the baseline calibration with more fine-grained sectoral calibrations at the two digit industry level. Note, however, that we run the model separately for each sector since the focus of the Melitz model more generally on on firm heterogeneity within countries. This allows us to study in detail the underlying heterogeneities driving the main results. We calibrate the following model parameters α, σ, k and f_x. $(1-\alpha)$ is the emission cost share in sectoral production. σ represents the elasticity of substitution between varieties, which we approximate by calculating a sales-weighted Herfindahl–Hirschman index (HHI) for each sector. k represents productivity dispersion measured by the ratio of the 95th productivity percentile and the 5th productivity percentile. Lastly, f_x are the fixed cost for exporting calibrated with the sectoral share of exporting firms.[9]

Table 1: Calibration with Prowess data

Sector Code	α	**HHI**	σ	φ **p95/p5**	k	**Exporter(%)**	f_x
(all) Manufacturing	0.90	0.018	3.98	1.66	6.72	1.69	6.17
(10) Food products	0.92	0.015	3.07	3.91	4.50	8.82	6.82
(11) Beverages	0.89	0.063	4.00	1.35	7.03	1.18	6.49
(12) Tobacco	0.91	0.563	3.98	2.30	6.09	4.60	5.59
(13) Textiles	0.86	0.011	3.93	1.53	6.85	1.73	6.91
(14) Wearing apparel	0.92	0.020	3.83	1.64	6.74	0.89	6.32
(15) Leather products	0.91	0.054	3.97	0.89	7.48	1.10	6.81
(16) Wood	0.89	0.109	3.34	1.32	7.06	5.56	6.96
(17) Paper	0.75	0.035	3.70	2.33	6.06	7.24	6.92
(19) Petroleum products	0.93	0.192	4.00	1.59	6.79	6.63	5.87
(20) Chemicals	0.85	0.012	3.98	2.36	6.03	9.97	5.97
(21) Pharmaceuticals	0.89	0.017	3.98	1.12	7.25	4.74	5.40
(22) Rubber and plastic	0.90	0.036	3.95	1.81	6.57	4.55	6.30
(24) Iron & Steel	0.84	0.214	3.66	1.46	6.92	5.19	6.81
(25) Fabricated metals	0.92	0.084	3.88	1.60	6.78	10.92	6.22
(26) Computer, electronic and optical products	0.94	0.020	3.98	1.58	6.80	8.62	5.23
(27) Electrical equipment	0.93	0.037	4.00	1.40	6.98	18.09	5.63
(28) Machinery	0.93	0.047	3.93	0.87	7.50	10.99	4.00
(29) Motor-vehicles	0.93	0.152	3.76	3.60	4.81	14.05	5.22
(30) Transport equipment	0.94	0.901	2.50	1.81	6.57	6.06	4.69
(31) Furniture	0.92	0.067	3.90	1.88	6.50	0.66	6.07
(32) Other manufacturing	0.95	0.068	3.98	1.65	6.73	5.51	7.00

Notes: This table reports parameter values for each Sector at the 2-digit-level. The aggregated manufacturing sector is displayed as "all". Remaining parameters are kept constant at $t_j = 1.0$, $\gamma_{ij} = 1.0$, $\tau = 1.1$, $b_i = b_j = 1.0$, $f_e = 2.5$, $L_i = L_j = 20$, $w_j = 1$ and $s = 1$. Data source: Prowess dx (CMIE)

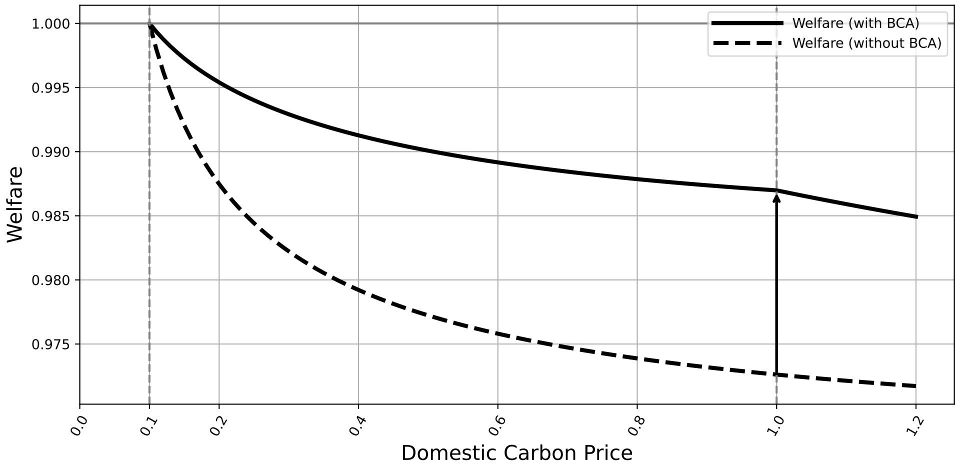
[9] A replication package containing our Mathematica workbook as well as further details on parameter calibration can be shared upon request.

5 Quantitative Analysis

5.1 Baseline: Manufacturing Sector

The main quantitative result of our analysis for the manufacturing sector are shown in Figure 2. Note that the x-axis plots the domestic carbon price t_i relative to the foreign carbon price, which is exogenously set to $t_j = 1.0$. Hence, the second vertical dashed line indicates the welfare if $t_i = t_j = 1$. The first dash line represents our baseline scenario, where $t_j = 0.10$ and $t_j = 1$. We choose the initial starting point of our analysis so that it resembles the ratio of net effective carbon carbon tax rates published by the OECD. In 2023, the net effective carbon rate of the European Union was 75.87 EUR and 7.23 EUR in India (OECD, 2023). Consequently, the net effective carbon rate in India amounts to just 11% of the corresponding rate in the EU ($t_i = 0.11 = t_j$). While the solid line indicates the Indian welfare for the case of a BCA imposed by foreign (the EU), the dashed line indicates the Indian welfare level for different domestic carbon prices when there is no BCA imposed. Note, however, that in both cases the EU has implemented a carbon price of $t_j = 1$. In both cases, welfare for India would reduce, if it would implement a domestic carbon price in response to the BCA. However, the welfare losses are smaller in the presence of a BCA. In consequence, under a BCA regime imposed by the trading partner, raising India's domestic carbon tax to $t_i = t_j = 1$ is associated with a welfare loss that is around 52% lower than the loss in a scenario without a BCA. Although the BCA reduces welfare costs, it is not sufficient to incentivize the implementation of a domestic carbon price when abstracting from environmental damage. In subsection 5.6, we augment economic welfare with an emissions-based environmental disutiltiy.

Figure 2: India: Overall Welfare (baseline normalized to 1)

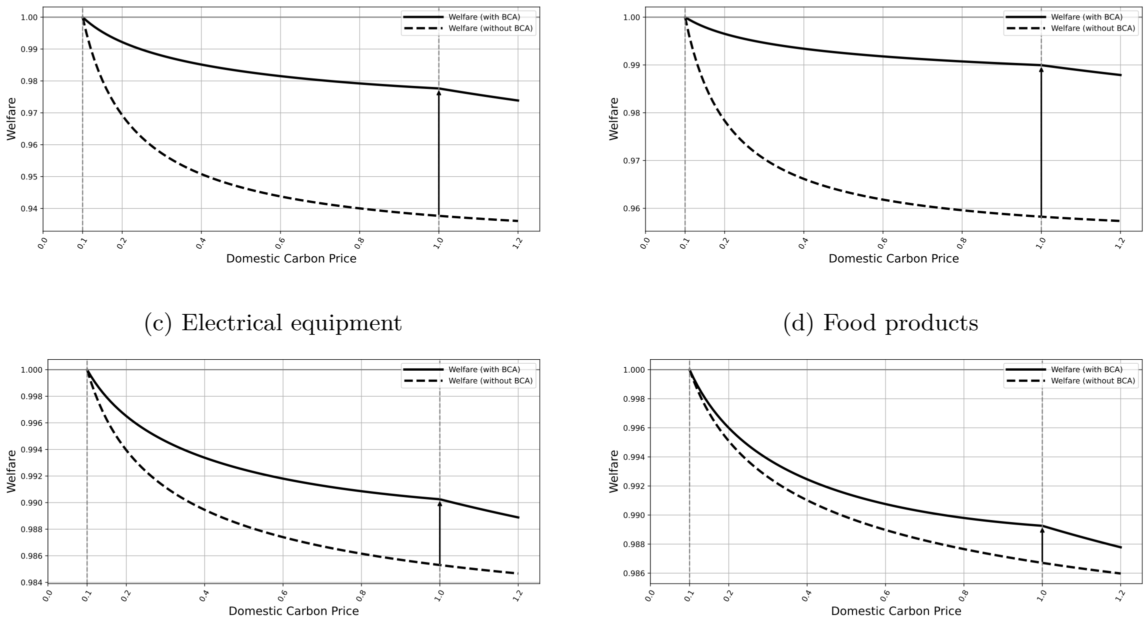


Notes: This plot uses parameter values for the aggregated manufacturing sector, displayed as "all" in Table 1. Remaining parameters are kept constant at $t_j = 1.0$, $\gamma_{ij} = 1.0$, $\tau = 1.1$, $b_i = b_j = 1.0$, $f_e = 2.5$, $L_i = L_j = 20$ and $w_j = 1$.

5.2 Sectoral heterogeneity

Figure 3 shows the results (with and without BCA) separately for the chemical sector, iron and steel, electric equipment and food products. It is straightforward to see that differences in welfare losses are substantially larger for chemicals and iron and steel. Specifically, the high emissions intensity and trade openness of these sectors increase their sensitivity to an emissions tax when a BCA is in place. While the the average share of exporters for the entire Manufacturing Sector is less than 2%, it is 10% of in Chemicals and 5% in the Iron and Steel sector respectively. Consequently, these sectors are characterized with lower fixed costs for exporting. In contrast, other sector who are dominated by domestic producers (e.g. food products) are less affected by the welfare smoothing effect of a BCA, when raising a domestic carbon price.

Figure 3: Comparison of Welfare Levels between Sectors



(a) Chemicals

(b) Iron & Steel

(c) Electrical equipment

(d) Food products

Notes: This plot uses parameter values for selected two-digit sectors in Table 1. Remaining parameters are kept constant at $t_j = 1.0$, $\gamma_{ij} = 1.0$, $\tau = 1.1$, $b_i = b_j = 1.0$, $f_e = 2.5$, $L_i = L_j = 20$ and $w_j = 1$.

Table 2 provides an overview of the welfare impacts for different levels of sectoral resolution. Column (2) and (3) depict the changes in welfare if the home country would raise a domestic carbon tax with or without being exposed to BCA. While there is a negative impact on economic welfare for both scenarios, it is evident that this effect is smaller when home is exposed by a CBAM. Put different, if India faces a BCA imposed by its trading partner (the EU), the economic welfare losses of introducing a carbon tax are around 52% lower than for the scenario without BCA exposure (1.30% vs. 2.74%). This difference is particularly strong for the sectors of Paper, Chemicals as well as Iron & Steel. Column (4) provides the relative welfare cost reduction induced by the presence of the BCA for all two-digit sectors.

Table 2: Calibration with Prowess data

Sector	$\Delta\%\ W_i\ t_i \rightarrow 1$ **with BCA**	$\Delta\%\ W_i\ t_i \rightarrow 1$ **w/o BCA**	$(1 - ratio)\Delta\%$)
(all) Manufacturing	-1.30	-2.74	52.46
(10) Food products	-1.07	-1.33	19.20
(11) Beverages	-1.14	-2.73	58.28
(12) Tobacco	-1.56	-2.51	37.88
(13) Textiles	-1.28	-4.31	70.20
(14) Wearing apparel	-0.93	-1.58	40.7
(15) Leather products	-0.72	-1.46	50.43
(16) Wood	-0.50	-1.59	68.94
(17) Paper	-2.05	-13.22	84.48
(19) Petroleum products	-1.00	-1.47	31.94
(20) Chemicals	-2.24	-6.23	64.13
(21) Pharmaceuticals	-1.26	-3.16	60.00
(22) Rubber and plastic	-1.31	-2.66	50.66
(24) Iron & Steel	-1.00	-4.18	75.94
(25) Fabricated metals	-1.01	-1.76	42.86
(26) Computer, electronic and optical products	-1.03	-1.43	28.15
(27) Electrical equipment	-0.97	-1.47	33.67
(28) Machinery	-1.20	-2.13	43.58
(29) Motor-vehicles	-1.82	-2.49	26.88
(30) Transport equipment	-0.24	-1.05	77.11
(31) Furniture	-1.09	-1.69	35.30
(32) Other manufacturing	-0.67	-0.78	15.01

Notes: This table reports the %-welfare change for India as a consequence of raising its emissions tax to the level of the EU (i.e. increasing t_i from 0.11 to 1.0) at the 2-digit-level. Note that this welfare measure abstracts from environmental damage. The aggregated manufacturing sector is displayed as "all". Remaining parameters are kept constant at $t_j = 1.0$, $\gamma_{ij} = 1.0$, $\tau = 1.1$, $b_i = b_j = 1.0$, $f_e = 2.5$, $L_i = L_j = 20$, $w_j = 1$ and $s = 1$.

5.3 The Role of Firm Heterogeneity

A central feature of the Melitz-model is the incorporation of firm heterogeneity. This impacts the welfare analysis of trade and environmental policies. In this subsection, we seek to highlight the significance of firm heterogeneity by contrasting with a counterfactual case where we reduce heterogeneity in the firm landscape. Here, Figure 4 plots the welfare effects of raising a domestic carbon tax with and without the presence of a BCA imposed by the trading partner. While panel (a) shows the baseline results with firm-level calibrated firm heterogeneity, panel (b) depicts a scenario where firm heterogeneity is substantially reduced.[10]

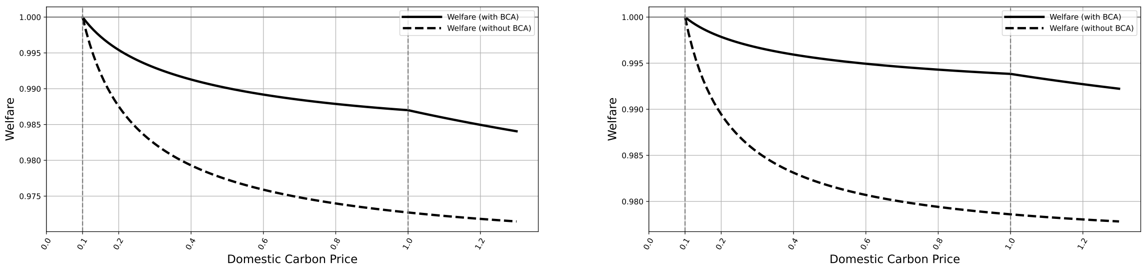
Figure 4 shows that reducing or switching off firm heterogeneity would lead to an underestimation of the welfare impacts of a domestic carbon tax. This clearly underscores the need

[10] Raising the shape parameter k of the firm distribution function leads to a more densely distributed range of firms, decreasing heterogeneity in productivity across firms. As an extreme case, parameter k approaching infinity would imply complete homogeneity of firm productivities.

for accounting for heterogeneity across firms when analyzing the welfare impact of a unilateral environmental policy reform in the context of a BCA. Furthermore, we observe that a reduction in firm heterogeneity corresponds to a significantly larger relative welfare cost reduction (approximately 61%) caused by the unilateral environmental reform when comparing the scenario without a Border Carbon Adjustment (BCA) to the scenario with a BCA.

Figure 4: India: Overall Welfare

(a) firm heterogeneity ”standard” (as in baseline) (b) firm heterogeneity ”low”



Notes: This plot uses parameter values for the aggregated manufacturing sector, displayed as "all" in Table 1. Remaining parameters are kept constant at $t_j = 1.0$, $\gamma_{ij} = 1.0$, $\tau = 1.1$, $f_e = 2.5$, $w_j = 1$, $L_j = 20$ and $b_j = 1.0$. Scenario ”standard” (left panel) refers to the baseline with $k = 6.72$, whereas scenario ”low” refers to a substantially higher shape parameter of $k = 8.5$, implying a more dense firm distribution.

5.4 Sensitivity to Country Asymmetries

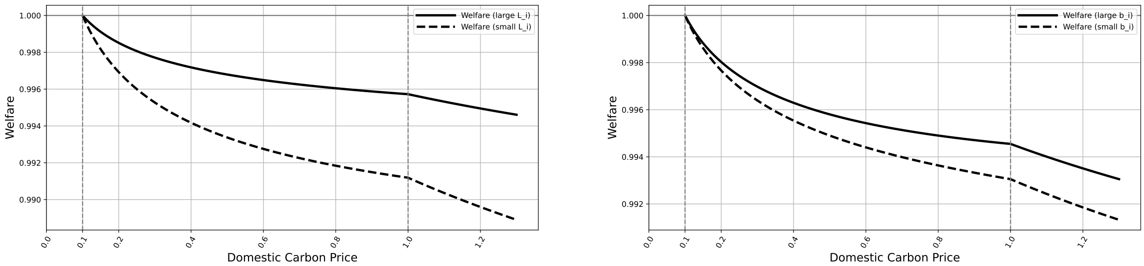
Since our model incorporates only two countries, there is no possibility for India (country i) to respond to the BCA imposed by its trading partner j (the EU) with an intensification of trade with other countries. In other words, all exports are affected by the BCA. However, in the current policy discussion it is only the EU that has implemented a CBAM and only a relatively small fraction of exports is affected by the EU-CBAM. Further, this means that countries such as India would still have the possibility to shift exports away from the EU to countries without environmental regulation. A simple way to partially pay account to these potential mechanisms without adding a third country in the model can be achieved by altering the size of the home country (India) relative to the foreign trading partner (EU).

The results are depicted in panel (a) of Figure 5. It highlights that welfare losses in response to a unilateral environmental reform under the presence of a BCA are decreasing in the size of the home country relative to the foreign country.

We add another dimension of across-country heterogeneity: Often it is argued, that the EU-CBAM poses specific challenges to developing and emerging economies due to substantial differences in productivity. Therefore, panel (b) depicts the results for different levels of productivity. As shown by the comparison of the solid and dashed lines, welfare losses decrease in country-specific average productivity. This means the larger difference in productivity between the BCA-imposing countries and its trading partner, the larger the welfare losses. This result shows that the incentive to introduce a domestic carbon price is further limited for low-productive economies.

Figure 5: India: Overall Welfare

(a) Varying country size (b) Varying country-specific productivity



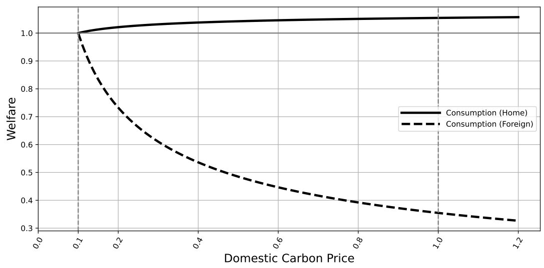
Notes: This plot uses parameter values for the aggregated manufacturing sector, displayed as "all" in Table 1. Remaining parameters are kept constant at $t_j = 1.0$, $\gamma_{ij} = 1.0$, $\tau = 1.1$, $f_e = 2.5$, $w_j = 1$, $L_j = 20$ and $b_j = 1.0$. Scenario "large L_i" (left panel) refers to a larger economy for India, with $L_i = 30$, whereas scenario "small L_i" refers to a smaller economy for India, with $L_i = 20$. Similarly, Scenario "large b_i" (left panel) refers to a more productive India, with $b_i = 1.1$, whereas scenario "small b_i" refers to a less productive India, with $b_i = 0.9$. Note that b_i represents the lower bound of the productivity pareto distribution and therefore mechanically impacts average productivity in country i.

5.5 Decomposition of welfare

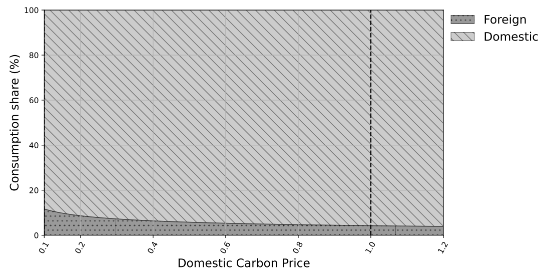
It is straightforward to decompose welfare of country i into domestically produced consumption and imported consumption. In the plots, baseline values are normalized to one. Importantly, the presence of the BCA fundamentally changes the effect of the emission tax increase on country i's imported consumption. As the emission tax increase strongly raises imported consumption, the relative welfare costs of environmental stringency are considerably lower when country i faces a BCA.

Figure 6: India: decomposition of effects on welfare

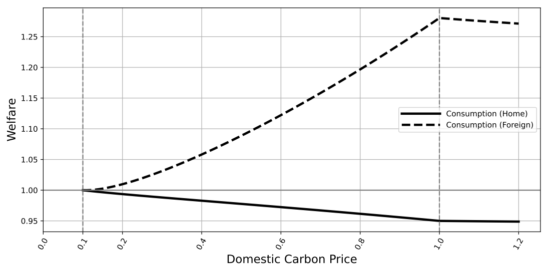
(a) Consumption without BCA



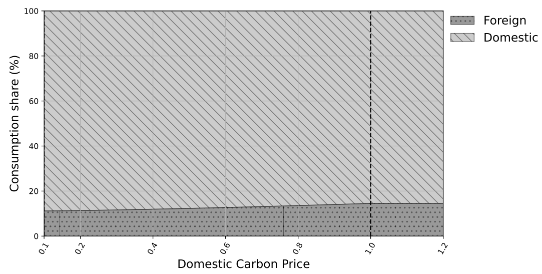
(b) Consumption shares (without BCA)



(c) Consumption with BCA



(d) Consumption shares (with BCA)



Notes: This plot uses parameter values for the aggregated manufacturing sector, displayed as "all" in Table 1. Remaining parameters are kept constant at $t_j = 1.0$, $\gamma_{ij} = 1.0$, $\tau = 1.1$, $b_i = b_j = 1.0$, $f_e = 2.5$, $L_i = L_j = 20$ and $w_j = 1$.

5.6 Welfare with Environmental Disutility

In this subsection, we add environmental disutility to the perspective of welfare. This adds a further level of complexity to our expression for welfare in country i:

$$W_i^D = \frac{W_i}{1 + \left(\frac{1}{\mu_d} * E_W\right)^2}, \tag{27}$$

where W_i refers to our standard welfare expression net of environmental disutility and $E_i + E_j = E_W$ denotes global emissions. Like Larch and Wanner (2024), we follow Shapiro (2016) and introduce μ_d as an inverse damage parameter governing the scale of disutility from global carbon emissions. Consumers regard emissions as a pure externality, hence emissions are irrelevant for individual consumption levels. Choosing this framework ensures that the social cost of carbon remains constant around the baseline level of global emissions. The inverse damage parameter μ_d is estimated following Shapiro (2016) using the baseline levels of W_i and E_w, converting a range of values for a social cost of carbon (SCC) ["10 EUR", "50 EUR", "100 EUR", "150 EUR", "200 EUR", "250 EUR", "300 EUR", "350 EUR"] into implicit monetary units in this stylized model framework. Furthermore, we assume that India, owing to its population size and geographical exposure, bears a share of 20% of global social carbon costs.

Figure 7 plots the welfare for different levels of India's domestic carbon price t_i while accounting for environmental disutiltiy. The plot shows the results for aa (conservative) global SCC estimate of 50 EUR per ton of carbon. When accounting for environmental disutility, welfare exhibits an inverted U-shape in relation to the domestic carbon tax due to the environmental damage avoided by carbon taxation. Hence, there is a positive, welfare-optimal level of carbon taxation.

As it can be seen in both panels, the presence of a BCA leads to higher optimal domestic carbon prices than without a BCA. However, at the given SCC level of 50 EUR, in both cases there is no incentive to impose a domestic carbon price higher than the foreign country.

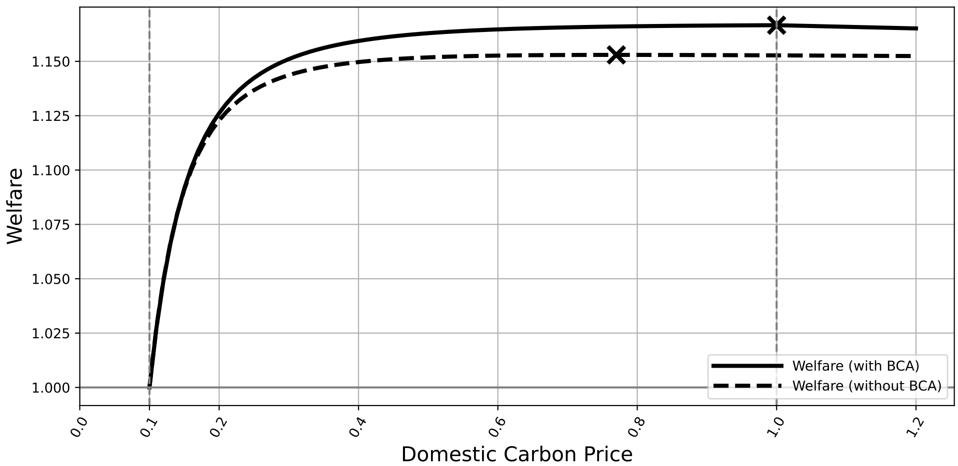


Figure 7: India: Welfare effects with environmental disutility (SCC set at 50 EUR)

Figure 8 plots the optimal domestic carbon price t_i for different levels of environmental damage, ranging from μ_d set at an SCC of 10 EUR up to μ_d set at 350 EUR per ton of carbon. Our analysis shows that the presence of a BCA "pushes" the optimal domestic carbon price t_i towards t_j. For low environmental damages (i.e. high values of μ_d), the presence of a BCA increases the optimal level of t_i , while for large environmental damages (i.e. low values of μ_d), the optimal t_i even shows to be higher in absence of a BCA.

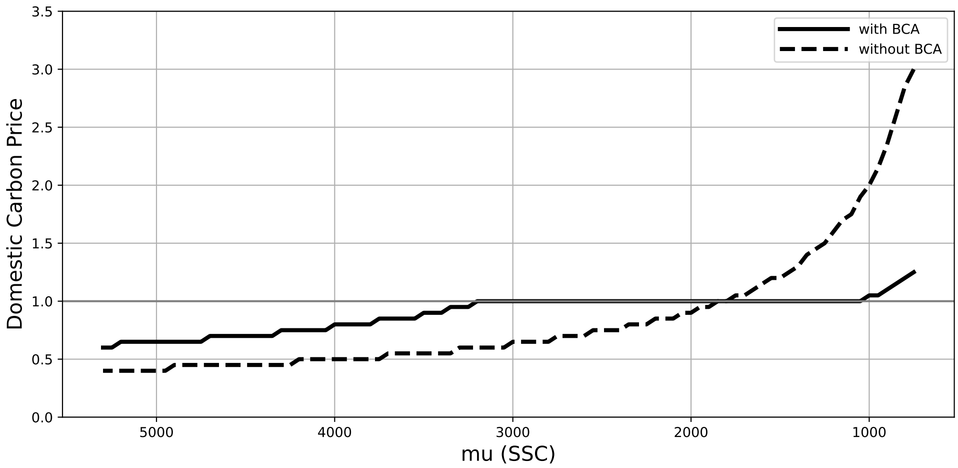


Figure 8: Optimal carbon tax for India with varying social costs of carbon

The underlying mechanism can be described as follows: For ranges of SCC that correspond to optimal values of t_i falling below the emissions tax level t_j of its trading partner, the presence of the BCA adds an additional welfare-enhancing effect of raising country i's domestic carbon tax: increasing t_i "melts" the border tariff by j, allowing for more trade (and imports) to country i. However, for ranges of SCC that translate into an optimal tax going beyond that of its trading partner, the benefit of 'melting' down the BCA is not given, weakening the marginal benefit of raising t_i and thus resulting into a lower optimal carbon tax for country i.

6 Conclusion and Outlook

In conclusion, carbon pricing, complemented by Border Carbon Adjustment Mechanisms (BCAs), represents a critical policy tool for mitigating carbon leakage and ensuring the effectiveness of domestic environmental regulations. Our analysis demonstrates that, for a country like India, aligning its emission tax with that of the EU under a BCA framework can significantly reduce the welfare costs of stricter environmental policies, even without accounting for environmental disutility. Specifically, the welfare cost reduction across all manufacturing sectors is approximately 52%, driven by enhanced consumption possibilities of imported varieties. Adding environmental disutility leads to an inverted U-shaped reaction of welfare to a unilateral emissions tax increase. In this extended setting, we find that the presence of a BCA introduces an additional welfare-enhancing channel for India, raising the welfare-optimal emissions tax under low and moderate social cost of carbon (SCC) scenarios. We also identify a range of SCC levels where matching the trading partner's carbon tax rate becomes optimal. However, under very high SCCs, the

BCA can reduce the welfare-optimal carbon tax, as exceeding the partner's tax rate yields no further tariff reductions while increasing the marginal disutility of stricter environmental policy.

Our model offers analytical tractability and delivers clear, intuitive insights into trade-related welfare mechanisms, making it well-suited for policy analysis. Building on this foundation, extending the framework to a multi-country, multi-sector setting with input–output linkages and structural differences in emissions cost shares presents a promising direction for future research, with the potential to further strengthen its quantitative precision.

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Appendix A Effect of Unilateral Reform $dt_i > 0$ on Cut-Offs

We analyze how an increase in country i's emissions tax, i.e. $\hat{t}_i$, affects the productivity cut-offs under two regimes: under regime (i), i.e. without the Border Carbon Adjustment (BCA) as well as under regime (ii), i.e. with BCA imposed by country j. Using log changes (hat notation), the comparative statics expressions for each scenario are derived as follows:

Appendix A.1 Without BCA

In the absence of CBAM, we can completely build on the analytical results of Egger et al. (2021). In hat notation, the change in country i's export cut-off can be written as:

$$\hat{\varphi}^*_{ij} = \left[-(1-\alpha)\frac{1+\tilde{f}^x\chi_j}{k}\left(\hat{t}_i - \hat{t}_j\right) + \left(\zeta + \frac{\tilde{f}^x\chi_j}{k}\right)\frac{1}{\rho}\hat{\gamma}_{ij} + \left(\zeta - \frac{1}{k}\right)\frac{1}{\rho}\hat{\gamma}_{ji}\right]\mathcal{A}^{-1}, \tag{28}$$

where the term $\mathcal{A}$ is strictly positive and defined as:

$$\mathcal{A} \equiv \left(1+\frac{f_x}{f_d}m_{ji}\right)\left(\frac{1+\alpha(\sigma-1)}{\sigma-1} - \frac{1}{k}\right) + \left(1+\frac{f_x}{f_d}m_{ij}\right)\left(\frac{1+\alpha(\sigma-1)}{\sigma-1} + \frac{\frac{f_x}{f_d}m_{ji}}{k}\right) > 0. \tag{29}$$

Thus, the effect of the unilateral reform on country i's export cut-off φ^*_{ij}, keeping emisisons tax t_j as well as add-valorem tariffs γ_{ij} and γ_{ji} constant, is given by:

$$\frac{\hat{\varphi^*_{ij}}}{\hat{t}_i} = \frac{-(1-\alpha)\left(1+\frac{f_x}{f_d}m_{ji}\right)}{\mathcal{A}k} < 0, \tag{30}$$

Again following Egger et al. (2021), we write the domestic cut-off for country i as a function of its export cut-off. This simplifies interpreting the sign of the effect on φ^*_{ii}:

$$\frac{\hat{\varphi^*_{ii}}}{\hat{t}_i} = -\frac{f_x}{f_d}m_{ij}\cdot\frac{\hat{\varphi^*_{ij}}}{\hat{t}_i} > 0, \tag{31}$$

where the negative sign follows due to the negative link to φ^*_{ij}.

Similarly, the effect on the export cut-off for country j, φ^*_{ji}, can be written as:

$$\frac{\hat{\varphi^*_{ji}}}{\hat{t}_i} = -\frac{1+\frac{f_x}{f_d}m_{ij}}{1+\frac{f_x}{f_d}m_{ji}}\cdot\frac{\hat{\varphi^*_{ij}}}{\hat{t}_i} > 0, \tag{32}$$

where the negative sign follows directly from the negative link between both export cut-offs.

Appendix A.2 With BCA

When BCA is implemented, the comparative statics adjust to incorporate the carbon tariff effect. In particular, country j's add-valorem tariff turns into a border carbon adjustment carbon tariff $\gamma_{ji} = 1 + Min[0, (t_j - t_i) * (1-\alpha)] > 1$. This establishes a negative link between country j's carbon tariff and country i's unilateral policy reform $dt_i > 0$.

Hence, the effect on φ^*_{ij} is complemented by a second summand in the numerator:

$$\frac{\hat{\varphi^*_{ij}}}{\hat{t}_i} = \frac{-(1-\alpha)\left[\left(1+\frac{f_x}{f_d}m_{ji}\right) + \left(\frac{1+\alpha(\sigma-1)}{\sigma-1}k - 1\right)\frac{1}{\rho}\right]}{\mathcal{A}k} < 0, \tag{33}$$

which goes in the same direction as the first summand, thereby reinforcing the negative effect for ranges where the border carbon tariff is in place (i.e. $t_i < t_j$).

The term $\mathcal{A}$ remains identical to the no-BCA case and continues to satisfy $\mathcal{A} > 0$.

Similarly, the expressions for φ^*_{ii} and φ^*_{ji} adjust to:

$$\frac{\hat{\varphi^*_{ii}}}{\hat{t_i}} = -\frac{f_x}{f_d} m_{ij} \cdot \frac{\hat{\varphi^*_{ij}}}{\hat{t_i}} > 0, \tag{34}$$

$$\frac{\hat{\varphi^*_{ji}}}{\hat{t_i}} = \frac{(1-\alpha)\left[\left(1+\frac{f_x}{f_d}m_{ij}\right) - \left(\frac{1+\alpha(\sigma-1)}{\sigma-1}k + \frac{f_x}{f_d}m_{ij}\right)\frac{1}{\rho}\right]}{\mathcal{A}k} < 0. \tag{35}$$

Importantly, for the export cut-off of country j, the newly added second summand in the numerator is negative and thereby outweighs the first summand, turning flipping the effect on country j's export cut-off upside down while country j's carbon tariff is in place (i.e. for $t_j > t_i$). The proof follows in the next subsection.

Appendix A.3 Proof for $(\hat{\varphi^*_{ji}}/\hat{t_i}) < 0$

Proof. Consider the expression

$$\frac{\hat{\varphi^*_{ji}}}{\hat{t_i}} = \frac{(1-\alpha)\left[\left(1+\frac{f_x}{f_d}m_{ij}\right) - \left(\frac{1+\alpha(\sigma-1)}{\sigma-1}\cdot k + \frac{f_x}{f_d}m_{ij}\right)\frac{1}{\rho}\right]}{\mathcal{A}k}, \tag{36}$$

where we assume $k > \sigma > 1$, $\alpha \in (0,1)$, $\mathcal{A} > 0$, $\rho = \frac{\sigma-1}{\sigma}$, so that $0 < \rho < 1$ as well as $\frac{f_x}{f_d}m_{ij} \geq 0$.

Since $1-\alpha > 0$, $\mathcal{A}k > 0$, and $\rho > 0$, the sign of the expression depends on the term inside the brackets:

$$\Delta \equiv \left(1+\frac{f_x}{f_d}m_{ij}\right) - \left(\frac{1+\alpha(\sigma-1)}{\sigma-1}\cdot k + \frac{f_x}{f_d}m_{ij}\right)\frac{1}{\rho}. \tag{37}$$

Substituting $\rho = \frac{\sigma-1}{\sigma}$ gives

$$\frac{1}{\rho} = \frac{\sigma}{\sigma-1} > 1. \tag{38}$$

Define:

$$A \equiv 1 + \frac{f_x}{f_d}m_{ij} > 0, \tag{39}$$

$$B \equiv \left(\frac{1+\alpha(\sigma-1)}{\sigma-1}\cdot k + \frac{f_x}{f_d}m_{ij}\right)\cdot\frac{\sigma}{\sigma-1} > 0. \tag{40}$$

Since $\frac{\sigma}{\sigma-1} > 1$ and $k > \sigma > 1$, it follows that

$$\frac{1+\alpha(\sigma-1)}{\sigma-1}\cdot k > 1. \tag{41}$$

Therefore,

$$B > \left(\frac{1+\alpha(\sigma-1)}{\sigma-1}\cdot k + \frac{f_x}{f_d}m_{ij}\right) > 1 + \frac{f_x}{f_d}m_{ij} = A, \tag{42}$$

which implies

$$\Delta = A - B < 0. \tag{43}$$

Hence, the numerator of the original expression is negative, while the denominator $\mathcal{A}k$ is positive, implying

$$\frac{\hat{\varphi}^*_{ji}}{\hat{t}_i} < 0. \tag{44}$$

$\square$