Designing Effective Carbon Border Adjustment with Minimal Information Requirements: Theory and Empirics

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Motivation: Why do we need Carbon Border Adjustment?

Paris Accords (2015) is a legally-binding international treaty on *climate change*, negotiated by 196 parties

- ⇒ long-term goal: keep the rise in global temperature to well below 2° C above pre-industrial levels (preferably to 1.5° C)
- ⇒ Emissions should reach net-zero by around 2050. To stay below 1.5° should reduce them by 50% by 2030

- Ambitious agreement, but while the EU contributes its fair share, most countries have not implemented sufficient emission reductions.
- October 23: EU introduces a carbon border adjustment mechanism (CBAM) to prevent *leakage* (i.e., production displacement abroad) associated with stringent EU emission trading system (ETS) and lack of equivalent policies abroad.

CBAM (Carbon Border Adjustment Mechanism)

Main objectives

1. Deter carbon leakage to other countries
2. Give incentives for CO_2 emissions reductions abroad

Implementation: regulation for importers

- calculate embedded CO_2 emissions of imports at plant level (direct and energy-related), fallback is country-specific CO2 intensity.
- Importers must buy CBAM certificates for imported embedded emissions at the ETS price
- Since computing carbon content is complex, CBAM applies only to few carbon-intensive sectors (aluminum, steel, fertilizers, hydrogen, energy)

Main limitations of CBAM

- Moral hazard: incentives to under-report carbon content necessitate costly monitoring and sanctioning
- Tremendous bureaucracy due to unrealistic data requirements
- Since CBAM applies to a small subset of sectors, incentives to offshore final goods production that use carbon-intensive intermediates
- Reshuffling of clean exports to the EU and dirty exports to third countries without global emission reductions
- Arbitrage opportunities: different exporters face different tax rates
- Political opposition from carbon-intensive exporting countries that would face high CBAM rates (mostly low-income)

CBAM: *levels playing field w.r.t carbon costs* but its high *ambitions* (foreign emission reductions) threaten its feasibility

LBAM (Leakage Border Adjustment Mechanism)

LBAM gives up goal of reducing foreign emissions and concentrates on eliminating leakage.

Recall what is driving carbon leakage:

EU carbon price:

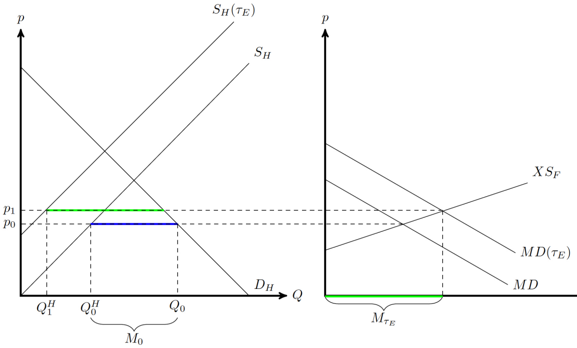
- reduces EU production of carbon intensive products
- increases demand for imported substitutes and reduces EU exports

$\Rightarrow$ **Emissions leakage**:
CO_2 embedded in increased imports to the EU and exports from third countries

LBAM: designed to exactly offset the change in imports and exports induced by EU ETS $\Rightarrow$ exact leakage offset

Carbon Leakage: Higher imports M_{τ_E} due to carbon price τ_E

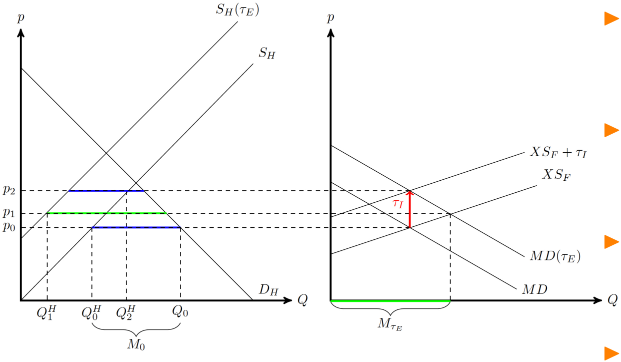
Simple model with home (H) and foreign (F) country



Carbon price τ_E is introduced in H

- Domestic supply S_H shifts out to $S_H(\tau)$
- Import demand MD_H shifts out to $MD_H(\tau)$
- International price increases from p_0 to p_1
- Leakage: Increase in import demand $\Delta M = M_{\tau_e} - M_0$

LBAM tariff τ_I resets imports to M_0: Zero Leakage



Impose LBAM tariff τ_I

- Drives a wedge between import demand MD_H and export supply XS_F
- Consumer price increases from p_1 to p_2, world price drops to p_0
- More domestic supply, reduction in imports by $-\Delta M$: leakage undone
- Negative Terms-of-Trade (ToT) effect of carbon tax is sterilized

Advantages of LBAM compared to CBAM

- LBAM does not require information on carbon intensity of foreign production.
- LBAM just requires info on EU carbon intensity, import demand and export supply elasticities
- LBAM an be easily applied to all sectors without costly bureaucracy ⇒ eliminates offshoring incentives
- LBAM is non-discriminatory (MFN): EU sets same LBAM rate vis-à-vis all partners ⇒ LBAM prevents arbitrage opportunities, reshuffling
- LBAM does not harm foreign exporters (avoids political opposition)

Quantitative Evaluation of Carbon Border Adjustment

- Quantitative trade model with monopolistic competition
- Derive LBAM rates from first principles and analyze welfare effects compared to CBAM
  - Model has a closed-form solution for LBAM rates, sector by sector
- Estimates and parameters needed to calibrate the model for 121 manufacturing sectors and the EU + 52 other countries
  - Import demand and export supply elasticities estimated using product-level import data for the EU
  - Elasticity of output to energy and physical input estimated from German firm-level micro data
  - Expenditure shares computed with product-level import data from COMTRADE and production data from UNIDO
  - Energy prices and carbon intensity from IEA and own data collection (to evaluate emission effects)

The different **policy schemes**

NO-BAM No border adjustment. Apart from the carbon price change in the EU27, there are no other policy changes. The EU carbon price rises from 15$ to 105$ per ton

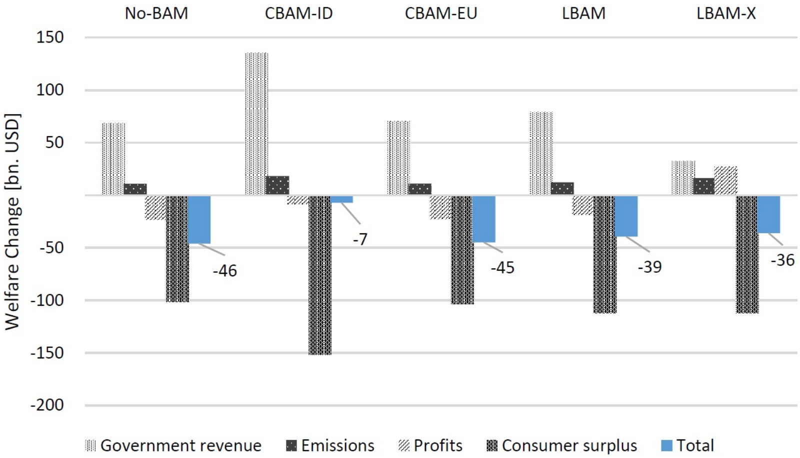
CBAM-ID 'Ideal' CBAM. The EU sets a CBAM that taxes the carbon content of imports in *all* sectors

CBAM-EU Current CBAM. EU CBAM on imports is limited to a set of sectors –aluminium, steel and iron, fertilisers, cement

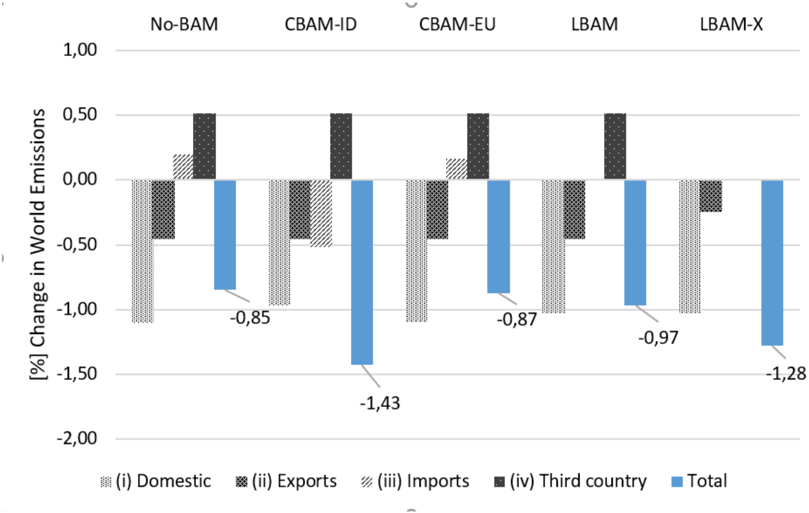
LBAM Tariffs on imports that eliminate bilateral import-related leakage in all sectors – tariffs exactly offset increases in imports induced by the domestic carbon price rise

LBAM-X In addition to import tariffs as in LBAM, the EU grants export subsidies that sterilize export-related leakage

Welfare effects of different policy schemes in the EU



Effects of different policy schemes on global emissions



Main findings

- Taxing domestic carbon emissions is *always* welfare detrimental for the EU $\Rightarrow$ It creates a competitive disadvantage for European manufacturers which justifies the introduction of a BAM
- CBAM-ID (i.e., taxing imports carbon content *in all sectors*) is the most effective way to mitigate welfare losses and to reduce emissions.
- CBAM-EU is the least effective BAM (welfare losses are higher and emission reductions are smaller than under LBAM schemes)
- Both LBAMs reach higher welfare and lower emissions compared to CBAM-EU or NO-BAM.
- Export subsidies are important for effectiveness of LBAM

Conclusions

- The EU's current CBAM mechanism will likely be ineffective in preventing leakage and protecting EU manufacturing
- CBAM has large monitoring burden (making it hard to extend to other sectors) and will face political opposition from carbon-intensive exporters
- We propose a simple alternative mechanism (LBAM) that (i) eliminates leakage effectively and (ii) preserves EU manufacturing activity and the Single Market.
- LBAM has much lower information requirements than CBAM, and is designed to minimize avoidance possibilities.
- LBAM does not harm foreign exporters and thereby avoids political opposition and being challenged at the WTO

APPENDIX

Change in EU bilateral imports

Gross Change in EU Bilateral Imports

	Mean	**Median**	**SD**	**Min**	**Max**
No-BAM	1.101	1.004	0.332	1	3.896
CBAM-ID	.901	.965	0.212	.002	5.743
CBAM-EU	1.099	1.003	0.333	.613	3.896
LBAM	1	1	0	1	1
LBAM-X	1	1	0	1	1

$\Rightarrow$ Without tariffs, leakage is severe. Tariffs are effective in eliminating leakage!

Change in EU tariffs

Gross Change in EU Tariffs

	Mean	Median	SD	Min	Max
No-BAM	1	1	0.000	1	1
CBAM-ID	1.083	1.057	0.088	1	2.056
CBAM-EU	1.003	1	0.017	1	1.392
LBAM	1.013	1.006	0.018	1	1.086
LBAM-X	1.013	1.006	0.018	1	1.086

- The average rise in tariffs needed to prevent leakage is quite modest (1.3%)!
- The average rise in CBAM tariffs would be quite large (8.8%)!

Change in EU Bilateral Exports

Gross Change in EU Bilateral Exports

	Mean	Median	SD	Min	Max
no-BAM	0.906	0.971	0.154	0.205	1
CBAM-ID	0.906	0.971	0.154	0.205	1
CBAM-EU	0.906	0.971	0.154	0.205	1
LBAM	0.906	0.971	0.154	0.205	1
LBAM-X	1	1	0.000	1	1

$\Rightarrow$ Without export subsidies, leakage is severe. Export subsidies are effective in eliminating leakage!

Change in EU Export Subsidies

Gross Change in EU Export Subsidies

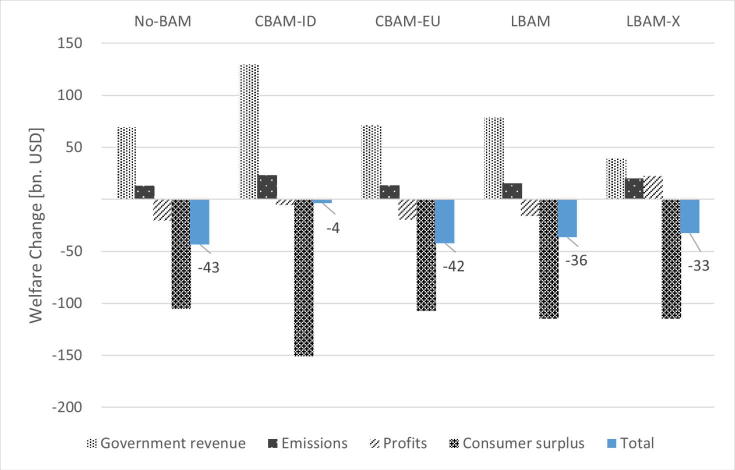
	Mean	Median	SD	Min	Max
No-BAM	1	1	0.000	1	1
CBAM-ID	1	1	0.000	1	1
CBAM-EU	1	1	0.000	1	1
LBAM	1	1	0.000	1	1
LBAM-X	.963	.97	0.026	.895	.998

0. Domestic Carbon Taxes Only; 1. Ideal CBAM; 2. Current CBAM; 3. LBAM Imports; 4. LBAM Imports+Exports

- The average export subsidy that holds exports constant is relatively small (3.6%)!

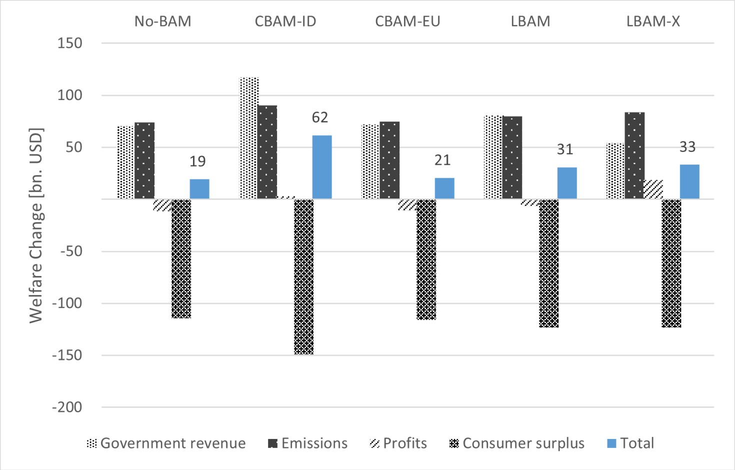
CARBON CLUB

Welfare Effects of a Carbon Club including EU, UK, CAN



Notes: (No-BAM) – no border adjustment; CBAM-ID – Ideal carbon border adjustment across all sectors; CBAM-EU – Current CBAM implementation in the EU; LBAM – Leakage Border Adjustment Mechanism applied to imports only; LBAM-X – Leakage Border Adjustment Mechanism applied to imports and exports. Other taxes are fixed. Countries outside the carbon club do not change their carbon prices.

Welfare Effects of a Carbon Club including EU, UK, CAN, US



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MODEL

Demand

$$U_i = C_{i0} + \int_s \eta_{is} \log C_{is} d_s - \theta \int_s e_s ds,$$

- e_s: global emissions in sector s-
- θ: disutility per unit of emissions

where

$$C_{is} = \left[\sum_{j=1}^{J} \int_0^{N_{ijs}} c_{ijs}(\omega)^{\frac{\varepsilon_s - 1}{\varepsilon_s}} d\omega \right]^{\frac{\varepsilon_s}{\varepsilon_s - 1}}$$

$$c_{ijs}(\omega) = \left(\frac{p_{ijs}(\omega)}{P_{ijs}} \right)^{-\varepsilon_s} C_{ijs}$$

$$C_{ijs} = \left(\frac{P_{ijs}}{P_{is}} \right)^{-\varepsilon_s} \eta_{is} P_{is}^{-1}$$

Production

- Monopolistic competition, fixed number of firms
- Production of country j for market i in sector s has variable returns to scale

$$y_{ijs} = \phi_{ijs} \left(\frac{z_{ijs}}{\beta_s} \right)^{\beta_s} \left(\frac{l_{ijs}}{\alpha_s} \right)^{\alpha_s} \tag{1}$$

- z_{ijs} is the energy use associated with the production
- l_{ijs} is a composite physical input (factors other than energy)
- ϕ_{ijs} is a productivity shifter.

$$TC_{ijs} = \left(\frac{y_{ijs}}{\phi_{ijs}} \right)^{\frac{1}{\alpha_s+\beta_s}} p_{Zj}^{\frac{\beta_s}{\alpha_s+\beta_s}} (\alpha_s + \beta_s)$$

- Define returns to scale $\gamma = 1/(\alpha + \beta) - 1$

Carbon Emissions and Carbon Tax

- d_j denotes the rate of carbon emissions per unit of energy in country j.
- Carbon emissions embodied in goods produced by sector s in country j for market i

$$e_{ijs} = d_j z_{ijs}$$

- per-unit carbon tax of τ_{Ej} Dollars per unit of carbon emissions.
- Unit of energy gross of the carbon tax is given by $p_{Zj} = \tilde{p}_{Zj} + d_j \tau_{Ej}$.

Sectoral Equilibrium

- Closed-form solution for y_{ijs}, p_{ijs} and P_{is} for all i, j and s:

$$y_{ijs} = \left(\eta_{is}\tau_{ijs}^{1-\varepsilon_s}\right)^{\frac{1}{\gamma_s\varepsilon_s+1}} \left(\phi_{ijs} p_{Zj}^{-\beta_s}\right)^{\frac{(\gamma_s+1)\varepsilon_s}{\gamma_s\varepsilon_s+1}} \left(\mu_s \tau_{Iijs}\tau_{Xijs}\right)^{\frac{-\varepsilon_s}{\gamma_s\varepsilon_s+1}} P_{is}^{\frac{\varepsilon_s-1}{\gamma_s\varepsilon_s+1}}$$

$$p_{ijs} = \eta_{is}^{\frac{\gamma_s}{\gamma_s\varepsilon_s+1}} \left(\tau_{ijs}\phi_{ijs}^{-1} p_{Zj}^{\beta_s}\right)^{\frac{\gamma_s+1}{\gamma_s\varepsilon_s+1}} \left(\mu_s \tau_{Iijs}\tau_{Xijs}\right)^{\frac{1}{\gamma_s\varepsilon_s+1}} P_{is}^{\frac{\gamma_s(\varepsilon_s-1)}{\gamma_s\varepsilon_s+1}}$$

$$P_{is}^{\frac{(\gamma_s+1)(1-\varepsilon_s)}{\gamma_s\varepsilon_s+1}} = \sum_{j=1}^{J} N_{ijs} \left(\eta_{is}^{\frac{\gamma_s}{\gamma_s\varepsilon_s+1}} \left(\tau_{ijs}\phi_{ijs}^{-1} p_{Zj}^{\beta_s}\right)^{\frac{\gamma_s+1}{\gamma_s\varepsilon_s+1}} \left(\mu_s \tau_{Iijs}\tau_{Xijs}\right)^{\frac{1}{\gamma_s\varepsilon_s+1}}\right)^{1-\varepsilon_s}$$

Equilibrium in Changes

- Define $\hat{X} \equiv \frac{X'}{X}$.
- Energy price change in reponse to change in carbon price: $\hat{p}_{Zj} = \frac{\tilde{p}_{Zj} + d_j \hat{\tau}_{Ej} \tau_{Ej}}{\tilde{p}_{Zj} + d_j \tau_{Ej}}$.
- Response of equilibrium variables:

$$
\begin{aligned}
\hat{y}_{ijs} &= \hat{p}_{Zj}^{-\beta_s \frac{(\gamma_s+1)\varepsilon_s}{\gamma_s \varepsilon_s + 1}} \left(\hat{\tau}_{Iijs} \hat{\tau}_{Xijs}\right)^{\frac{-\varepsilon_s}{\gamma_s \varepsilon_s + 1}} \hat{P}_{is}^{\frac{\varepsilon_s - 1}{\gamma_s \varepsilon_s + 1}} \\
\hat{p}_{ijs} &= \hat{p}_{Zj}^{\beta_s \frac{\gamma_s+1}{\gamma_s \varepsilon_s + 1}} \left(\hat{\tau}_{Iijs} \hat{\tau}_{Xijs}\right)^{\frac{1}{\gamma_s \varepsilon_s + 1}} \hat{P}_{is}^{\frac{\gamma_s(\varepsilon_s - 1)}{\gamma_s \varepsilon_s + 1}} .
\end{aligned}
$$

$$\hat{c}_{ijs} = \hat{C}_{ijs} = \hat{y}_{ijs}$$

$$
\hat{P}_{is}^{\frac{(1+\gamma_s)(1-\varepsilon_s)}{\gamma_s \varepsilon_s + 1}} = \sum_{j=1}^{J} \delta_{ijs} \hat{p}_{Zj}^{\beta_s \frac{(\gamma_s+1)(1-\varepsilon_s)}{\gamma_s \varepsilon_s + 1}} \left(\hat{\tau}_{Iijs} \hat{\tau}_{Xijs}\right)^{\frac{1-\varepsilon_s}{\gamma_s \varepsilon_s + 1}},
$$

where δ_{ijs} are initial absorption shares of country i on goods produced by country j.

A unilateral carbon-price increase without border adjustment

- Response of home sales to domestic market:

$$\hat{y}_{iis} = \hat{p}_{Zi}^{\frac{-\beta_s \ (\gamma_s+1)\varepsilon_s}{1+\varepsilon_s\gamma_s}} \left[\delta_{iis}\hat{p}_{Zi}^{\frac{\beta_s(1+\gamma_s)(1-\varepsilon_s)}{1+\varepsilon_s\gamma_s}} + 1 - \delta_{iis}\right]^{\frac{-1}{1+\gamma_s}} < 1.$$

- Domestic import response:

$$\hat{y}_{ijs} = \left[\delta_{iis}\hat{p}_{Zi}^{\frac{\beta_s(1+\gamma_s)(1-\varepsilon_s)}{1+\varepsilon_s\gamma_s}} + 1 - \delta_{iis}\right]^{\frac{-1}{1+\gamma_s}} > 1$$

- Domestic export response:

$$\hat{y}_{jis} = \hat{p}_{Zi}^{\frac{-\beta_s \ (\gamma_s+1)\varepsilon_s}{1+\varepsilon_s\gamma_s}} \left[\delta_{jis}\hat{p}_{Zi}^{\frac{\beta_s(1+\gamma_s)(1-\varepsilon_s)}{1+\varepsilon_s\gamma_s}} + 1 - \delta_{jis}\right]^{\frac{-1}{1+\gamma_s}} < 1$$

Global emission changes in response to domestic policies

$$\hat{e}_s = \underbrace{\hat{p}_{Zi}^{\beta_s(1+\gamma_s)-1}\tilde{\sigma}_{iis}\hat{y}_{iis}^{(1+\gamma_s)}}_{\substack{\textbf{(i)}\textit{Domestic emission changes due to a change} \\ \textit{in production of domestically} \\ \textit{consumed and produced goods}}} + \underbrace{\hat{p}_{Zi}^{\beta_s(1+\gamma_s)-1}\sum_{j\neq i}^{J}\tilde{\sigma}_{jis}\hat{y}_{jis}^{1+\gamma_s}}_{\substack{\textbf{(ii)}\textit{Domestic emission changes due to changes} \\ \textit{in exports}}}$$

$$+ \underbrace{\sum_{j\neq i}^{J}\tilde{\sigma}_{ijs}\hat{p}_{Zj}^{\beta_s(1+\gamma_s)-1}\hat{y}_{ijs}^{1+\gamma_s}}_{\substack{\textbf{(iii)}\textit{Foreign emission changes due to changes} \\ \textit{in imports}}} + \underbrace{\sum_{k\neq i}^{J}\sum_{j\neq i}^{J}\tilde{\sigma}_{jks}\hat{p}_{Zk}^{\beta_s(1+\gamma_s)-1}\hat{y}_{jks}^{1+\gamma_s}}_{\substack{\textbf{(iv)}\textit{Foreign emission changes due to changes in} \\ \textit{production of goods consumed and produced} \\ \textit{in the rest of the world}}}$$

- $\tilde{\sigma}_{ijs}$ initial sales shares of country-j firms in market i.
- part of (i) & (iii): import leakage
- (ii) & (iv): export leakage

LBAM Tariffs and Export Subsidies

- Holding aggregate imports constant without discrimination in response to a change in τ_{Ei} implies the following condition:

$$\hat{\tau}_{Iis}^{\frac{-\varepsilon_s(1+\gamma_s)}{\gamma_s\varepsilon_s+1}} = \delta_{iis}\hat{p}_{Zi}^{\frac{\beta_s(\gamma_s+1)(1-\varepsilon_s)}{\gamma_s\varepsilon_s+1}} + (1-\delta_{iis})\hat{\tau}_{Iis}^{\frac{1-\varepsilon_s}{\gamma_s\varepsilon_s+1}} \tag{2}$$

- Holding aggregate exports constant requires setting a non-discriminatory export subsidy that is independent of the export destination and equal to the pass-through: $\hat{\tau}_{Xi} = \hat{p}_{Zi}^{-\beta_s(\gamma_s+1)} < 1$,