How does trade adjustment influence national inventory of open economies?

Accounting for embodied carbon emissions based on the multi-region input-output model

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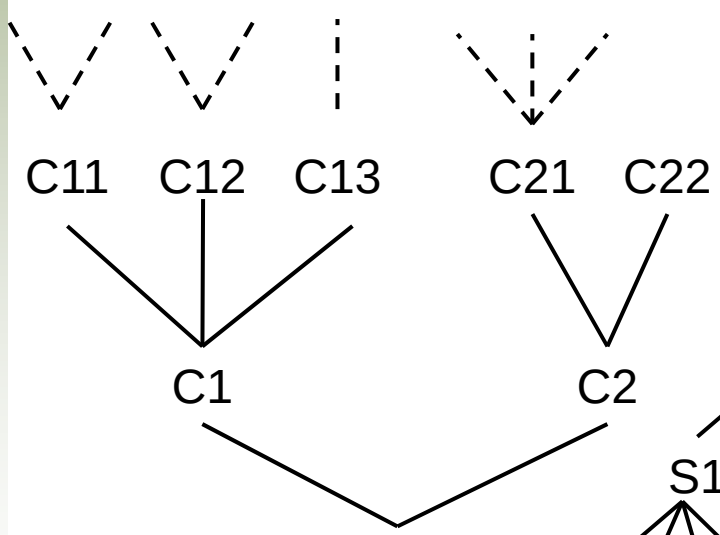
Embodied Emissions in Traded Goods

- Hidden impacts of traded goods: emissions emitted from each upstream stage of the supply chain of a product, which used or consumed by the downstream stage or consumer.
- Annex I and non-Annex I countries in the UNFCCC and carbon leakage issue and competitiveness issue.
- Current national GHG inventory and accounting method based on the territorial emissions (IPCC, 1996)
- A large number of literature indicated the importance of embodied carbon in national and global emissions (e.g. 12% at global level).

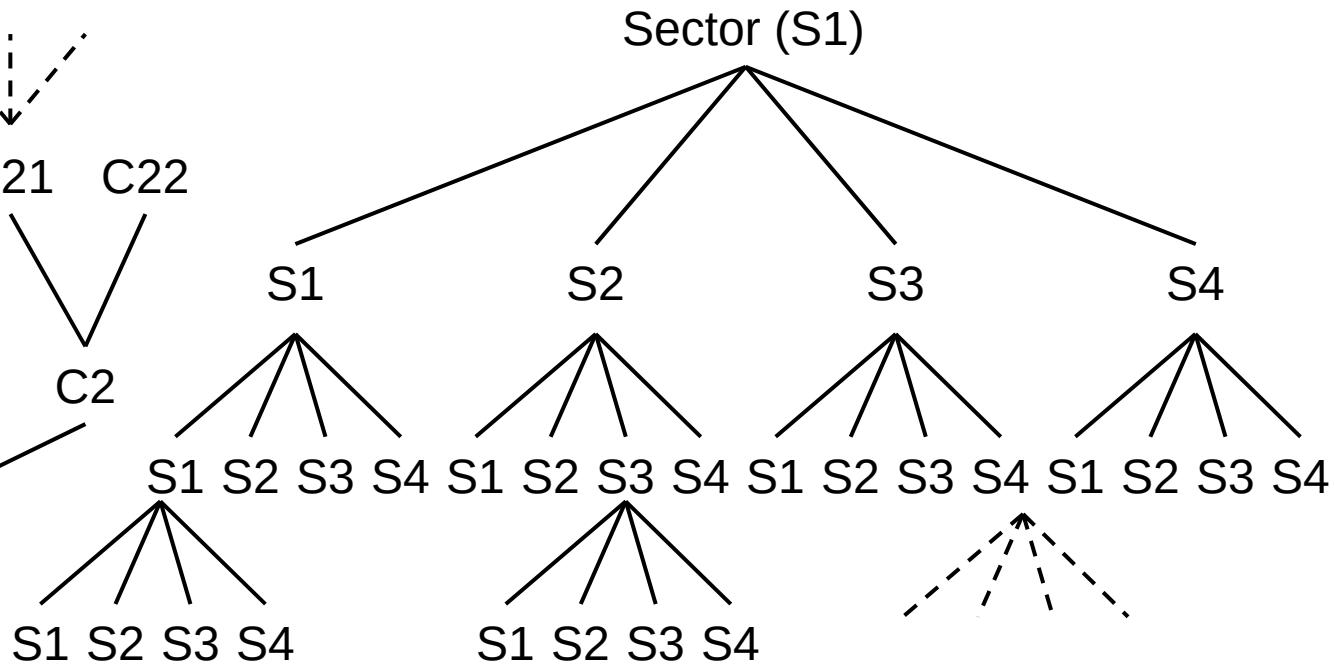
How to calculate embodied emissions?

Bottom-up method (life-cycle analysis) and top-down method (input-output analysis), and hybrid life-cycle analysis.

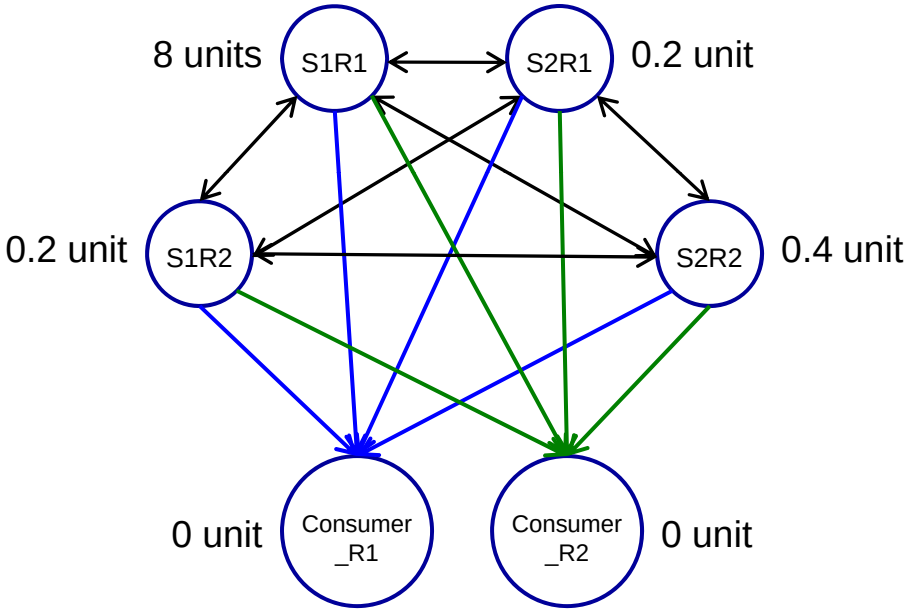
Life-cycle analysis



Input-output analysis



Multilateral Trade System



Three sets of elements

- Countries/regions;
- Sectors;
- Actors (upstream producers vs. downstream producers and final consumers).

Multi-region IO Framework

		Intermediate Demand				Final Demand		Export to ROW	Total Output
		S1R1	S2R1	S1R2	S2R2	R1	R2		
Supply	S1R1	X_{11}^{11}	X_{12}^{11}	X_{11}^{12}	X_{12}^{12}	F_1^{11}	F_1^{12}	E_1^{1ROW}	X_1^1
	S2R1	X_{21}^{11}	X_{22}^{11}	X_{21}^{12}	X_{22}^{12}	F_2^{11}	F_2^{12}	E_2^{1ROW}	X_2^1
	S1R2	X_{11}^{21}	X_{12}^{21}	X_{11}^{22}	X_{12}^{22}	F_1^{21}	F_1^{22}	E_1^{2ROW}	X_1^2
	S2R2	X_{21}^{21}	X_{22}^{21}	X_{21}^{22}	X_{22}^{22}	F_2^{21}	F_2^{22}	E_2^{2ROW}	X_2^2
Import from ROW		M_1^{ROW1}	M_2^{ROW1}	M_1^{ROW2}	M_2^{ROW2}				
Value-added		V_1^1	V_2^1	V_1^2	V_2^2				
Total input		X_1^1	X_2^1	X_1^2	X_2^2				

$$X = AX + F + E$$

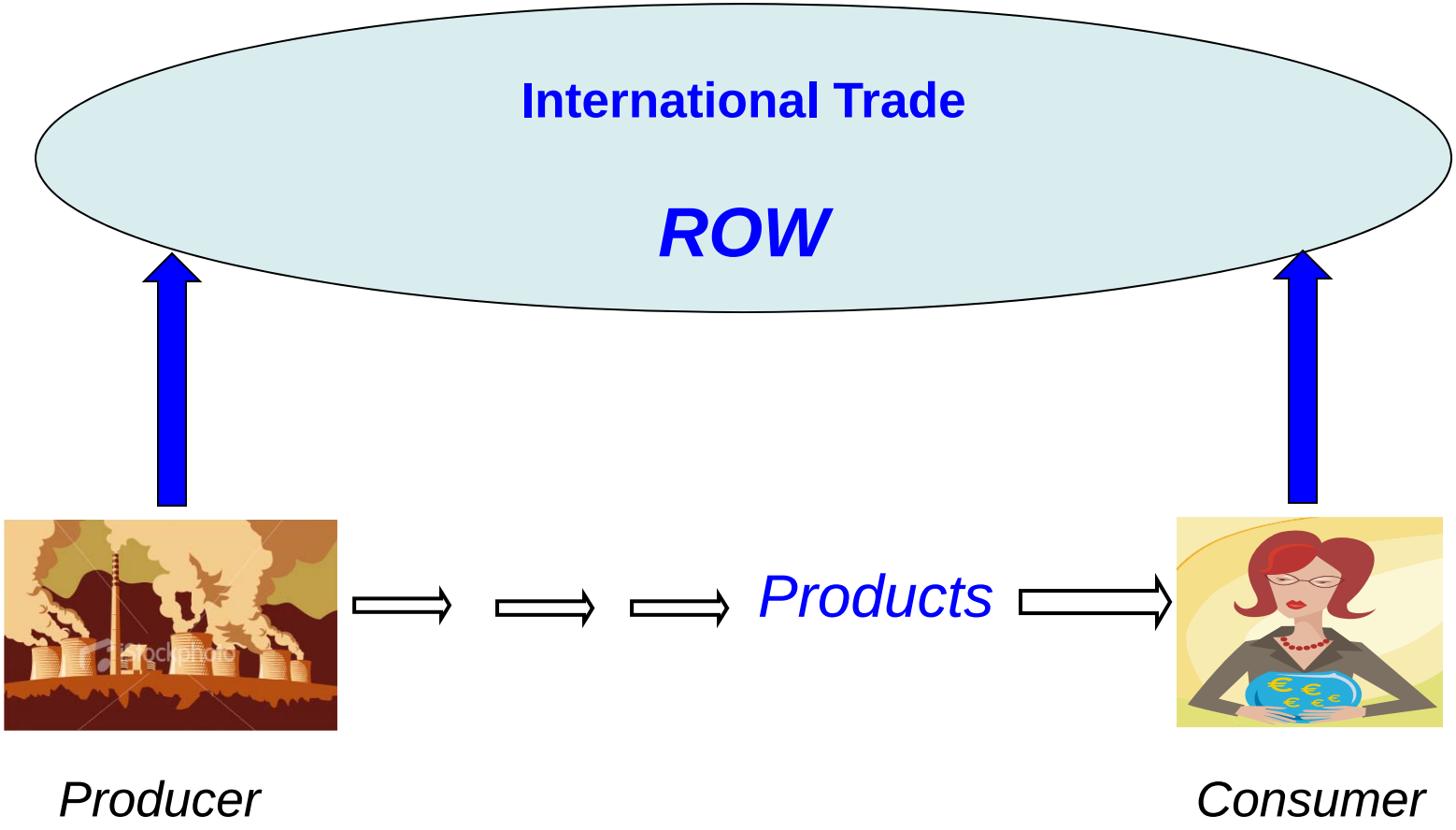
Two Types of Multipliers

$$\begin{pmatrix} X^1 \\ X^2 \\ \vdots \\ X^n \end{pmatrix} = (I-A)^{-1}\left[\begin{pmatrix} \sum_s F^{1s} \\ \sum_s F^{2s} \\ \vdots \\ \sum_s F^{ns} \end{pmatrix} + \begin{pmatrix} E^{1ROW} \\ E^{2ROW} \\ \vdots \\ E^{nROW} \end{pmatrix}\right] = \begin{pmatrix} B^{11} & B^{12} & \cdots & B^{1n} \\ B^{21} & B^{22} & \cdots & B^{2n} \\ \vdots & \vdots & \ddots & \vdots \\ B^{n1} & B^{n2} & \cdots & B^{nn} \end{pmatrix}\left[\begin{pmatrix} \sum_s F^{1s} \\ \sum_s F^{2s} \\ \vdots \\ \sum_s F^{ns} \end{pmatrix} + \begin{pmatrix} E^{1ROW} \\ E^{2ROW} \\ \vdots \\ E^{nROW} \end{pmatrix}\right]$$

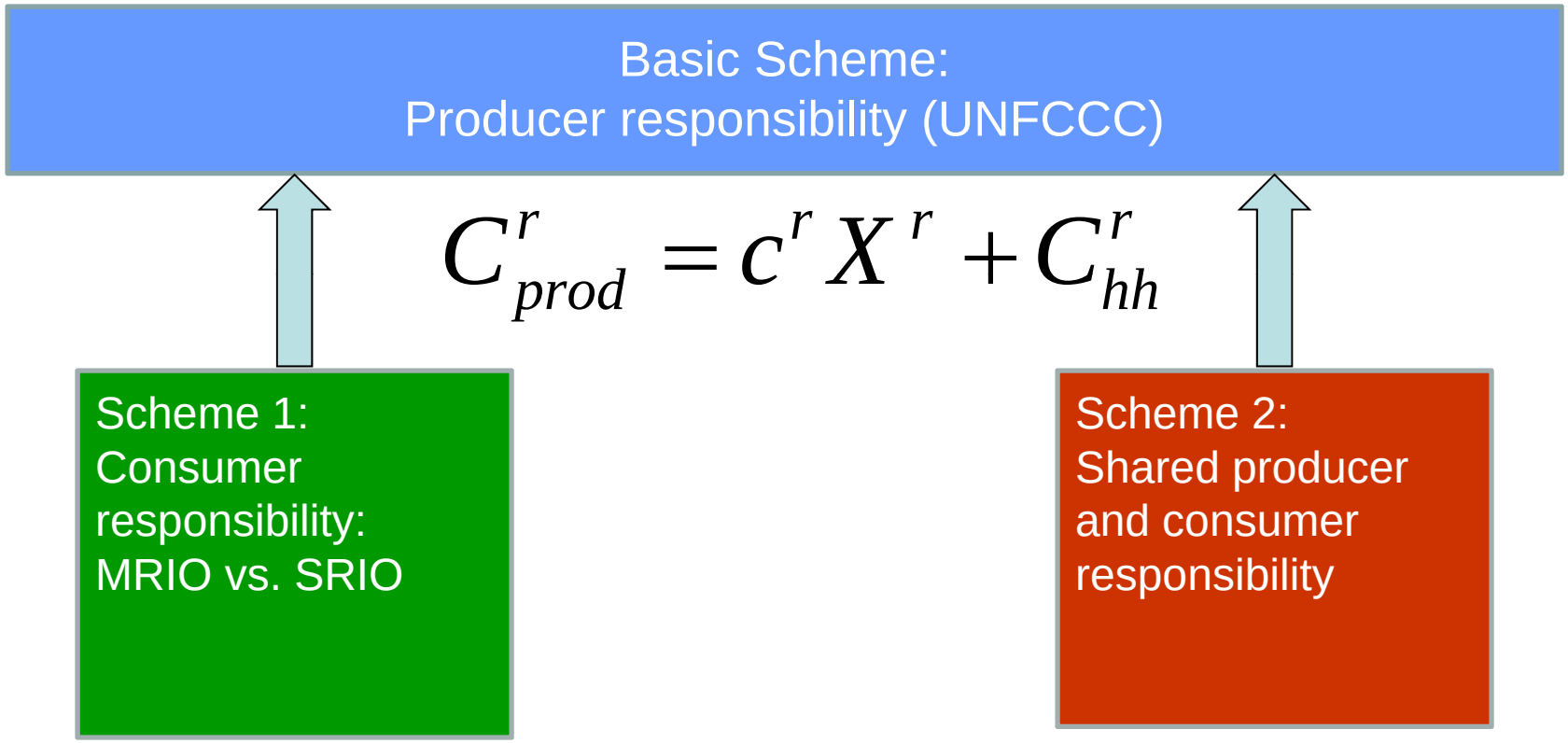
$$\begin{pmatrix} X^1 \\ X^2 \\ \vdots \\ X^n \end{pmatrix} = \begin{pmatrix} (I-A^{11})^{-1} & 0 & \cdots & 0 \\ 0 & (I-A^{22})^{-1} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & (I-A^{nn})^{-1} \end{pmatrix} \times$$

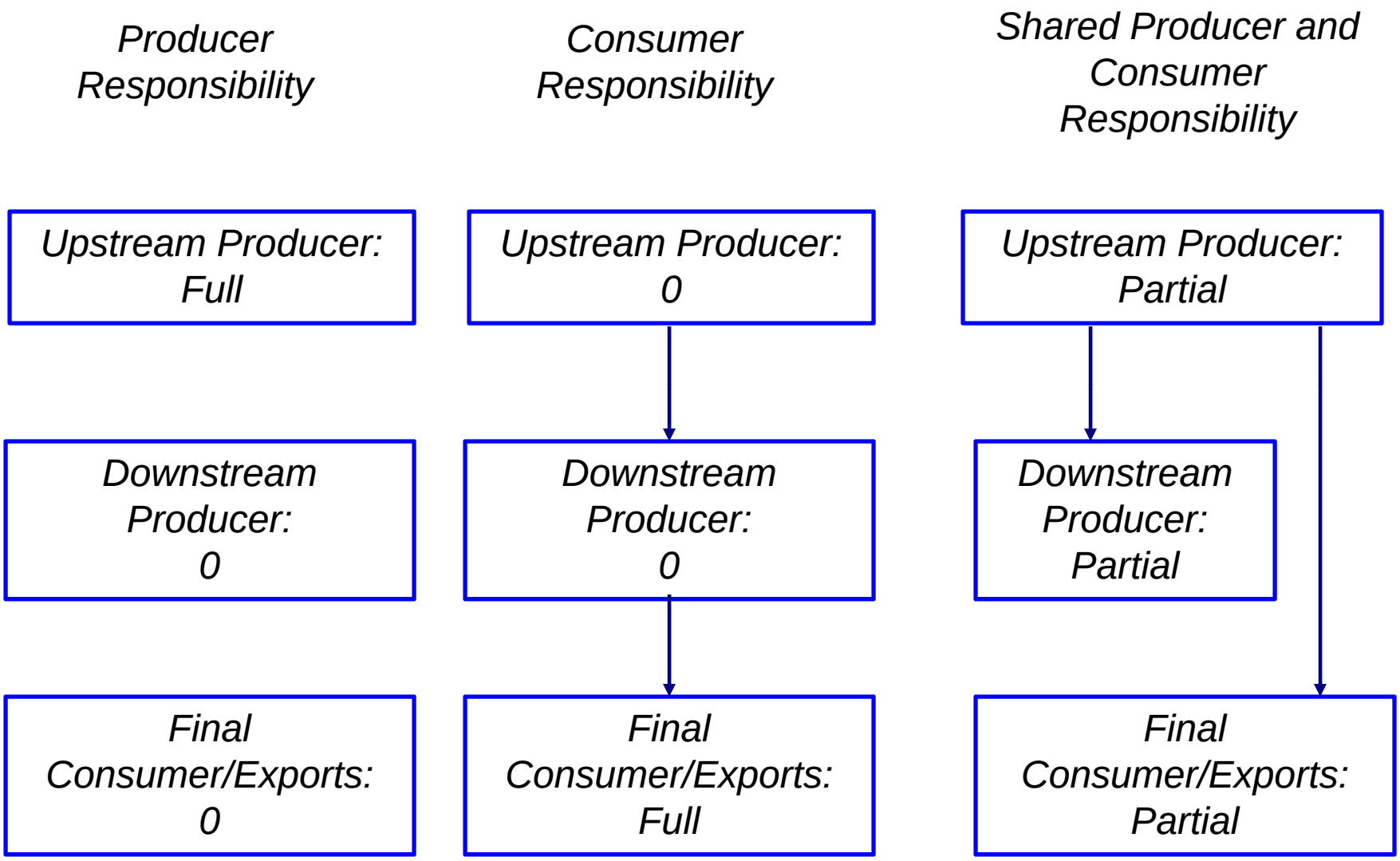
$$\left[\begin{pmatrix} \sum_{s\neq 1} A^{1s}X^s \\ \sum_{s\neq 2} A^{2s}X^s \\ \vdots \\ \sum_{s\neq n} A^{ns}X^s \end{pmatrix} + \begin{pmatrix} F^{11} + \sum_{s\neq 1} F^{1s} \\ F^{22} + \sum_{s\neq 2} F^{2s} \\ \vdots \\ F^{nn} + \sum_{s\neq n} F^{ns} \end{pmatrix} + \begin{pmatrix} E^{1ROW} \\ E^{2ROW} \\ \vdots \\ E^{nROW} \end{pmatrix}\right]$$

How to allocate responsibility for embodied emissions?



National Accounting Adjusted for Trade




Producer Responsibility
Consumer Responsibility
Shared Producer and Consumer Responsibility
Upstream Producer: Full
Upstream Producer: 0
Upstream Producer: Partial
Downstream Producer: 0
Downstream Producer: 0
Downstream Producer: Partial
Final Consumer/Exports: 0
Final Consumer/Exports: Full
Final Consumer/Exports: Partial

Data

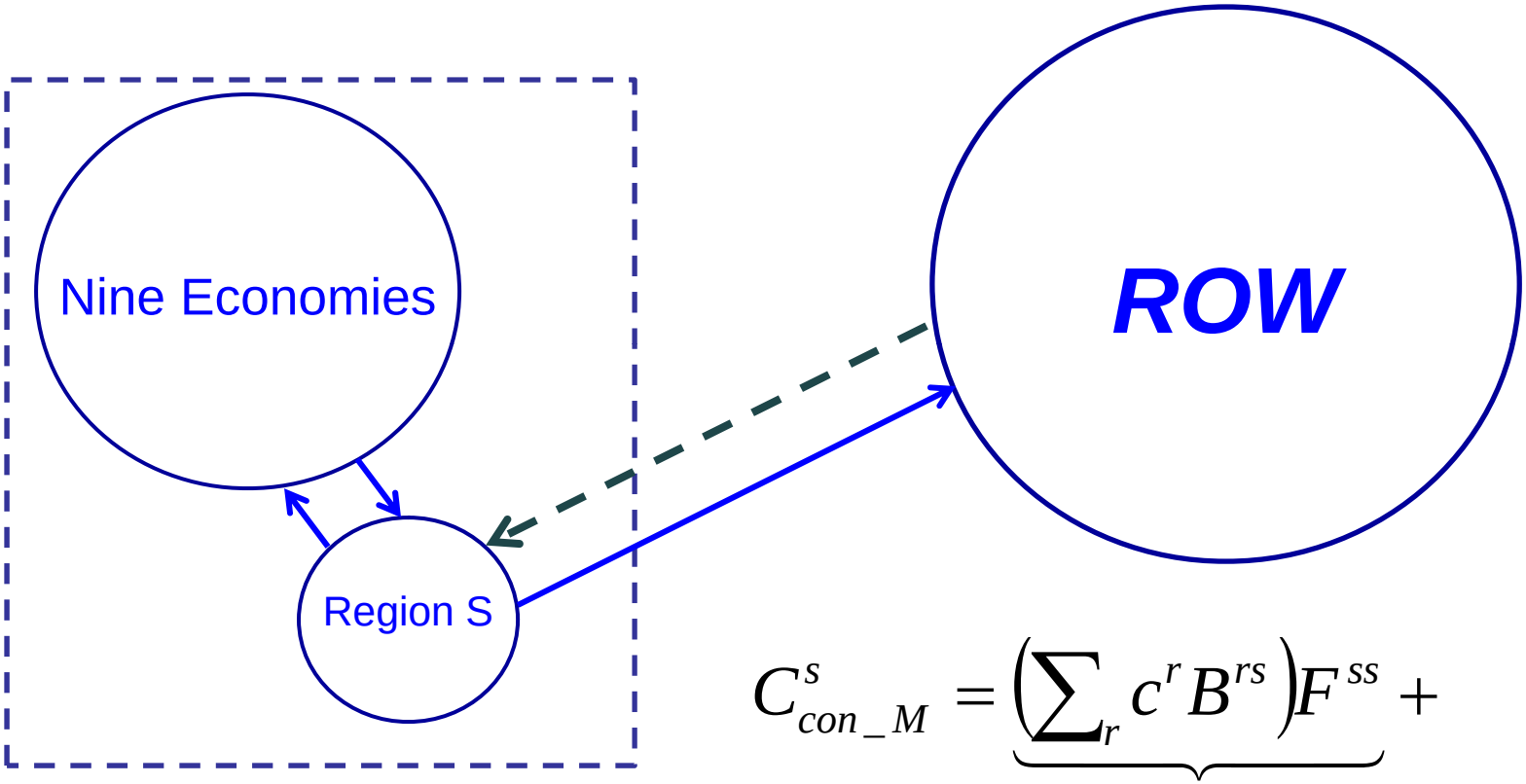
- Ten economies:

  IDN, MYS, PHL, SGP, THA, CHN, TWN, ROK, JPN, USA, ROW

- 10-region 24-sector Asian Input-output (MRIO) Table 2000 (IDE-JETRO)

- GTAP E-database (2001) for carbon emissions

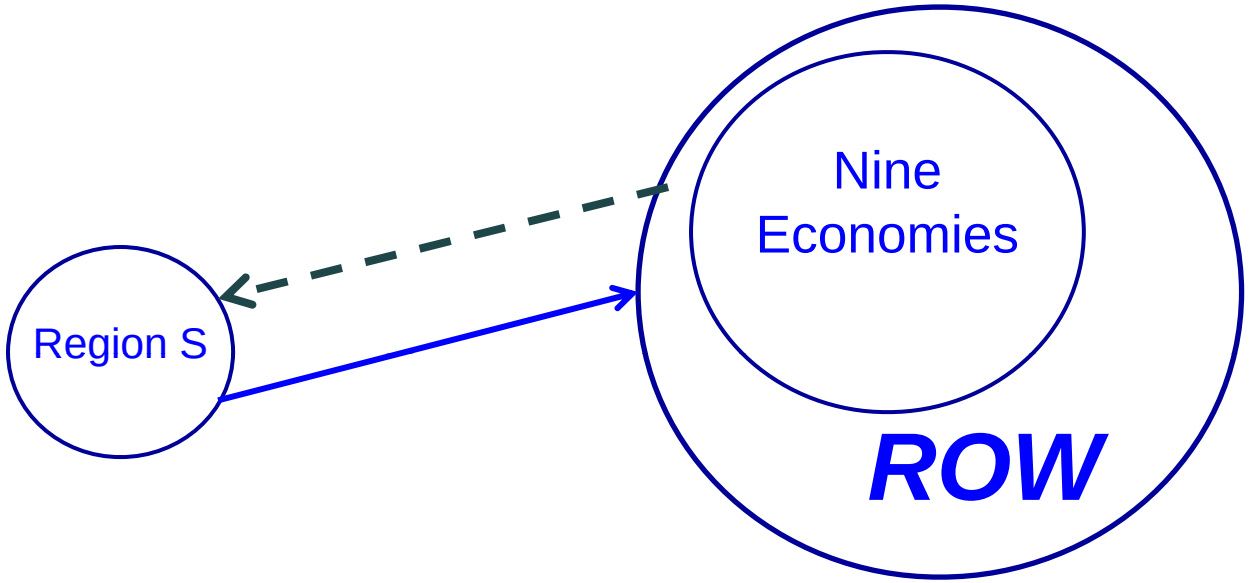
Consumer Responsibility: Sch1-MRIO



$$C^{s}_{con\_M} = \underbrace{\left(\sum\nolimits_{r} c^{r} B^{rs}\right) F^{ss}}_{P1\_M} +$$

$$\underbrace{\sum\nolimits_{n \neq s} \left[\left(\sum\nolimits_{r} c^{r} B^{rn}\right) F^{ns}\right]}_{P2\_M} + \underbrace{C^{s}_{im}}_{P3} + \underbrace{C^{s}_{hh}}_{P4}$$

Consumer Responsibility: Sch1-SRIO



$$C^{s}_{con\_S} = \underbrace{\left[c^{s}\left(I - A^{ss}\right)^{-1}\right]F^{ss}}_{P1_S} +$$

$$\underbrace{\sum_{n \neq s}\left[\left(c^{w}B^{w}\right)\left(A^{ns}X^{s} + F^{ns}\right)\right]}_{P2_S} + \underbrace{C^{s}_{im}}_{P3} + \underbrace{C^{s}_{hh}}_{P4}$$

Trade Balance of CO_2

- Emissions embodied in imports

$$\underbrace{\sum_{n \neq s} \left[\left(\sum_r c^r B^{rn} \right) F^{ns} \right]}_{P2_M} + \underbrace{C_{im}^s}_{P3}$$

- Emissions embodied in exports

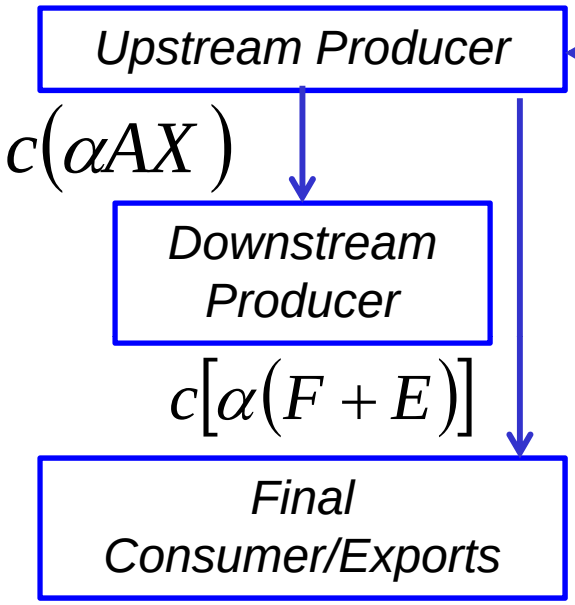
$$P5_M = \sum_{n \neq s} \left[\left(\sum_r c^r B^{rs} \right) F^{sn} \right]$$

$$P6_M = \left(\sum_r c^r B^{rs} \right) E^{sROW}$$

- Trade balance

$$C_{tb\_M}^s = (P5_M + P6_M) - (P2_M + P3)$$

Shared Producer and Consumer Responsibility: Sch2-MRIO



$$c\left[(1-\alpha)\left(AX+F+E\right)\right]$$

$$c\left(\alpha AX\right)$$

$$c\left[\alpha\left(F+E\right)\right]$$

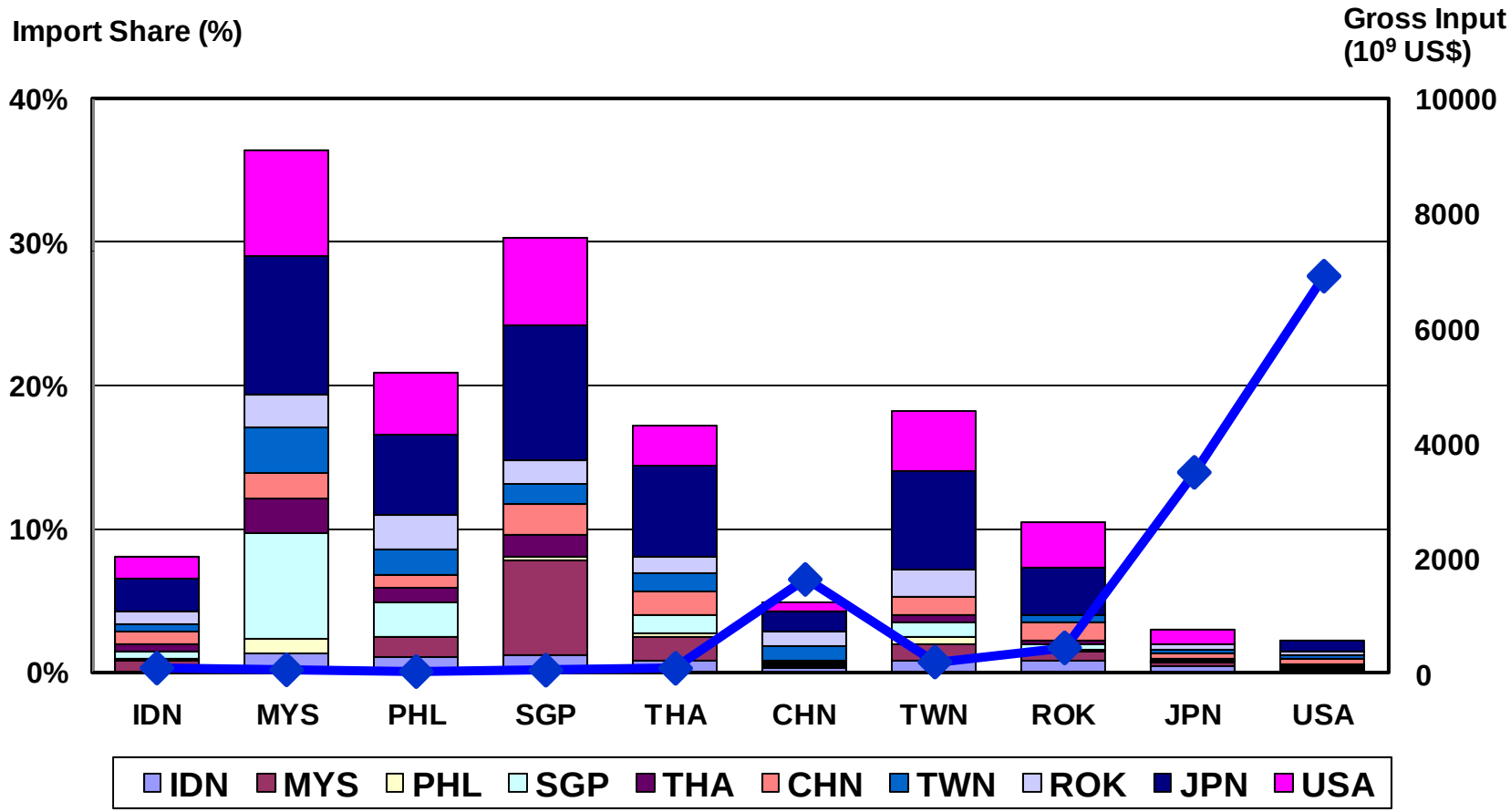
$$cX = c(AX+F+E)$$

$$= \underbrace{c\left[(1-\alpha)\left(AX+F+E\right)\right]}_{C1\text{: upstream producer}} +$$

$$\underbrace{c\left(\alpha AX\right)}_{C2\text{: downstream producer}} + \underbrace{c\left[\alpha\left(F+E\right)\right]}_{C3\text{: final consumers and exports}}$$

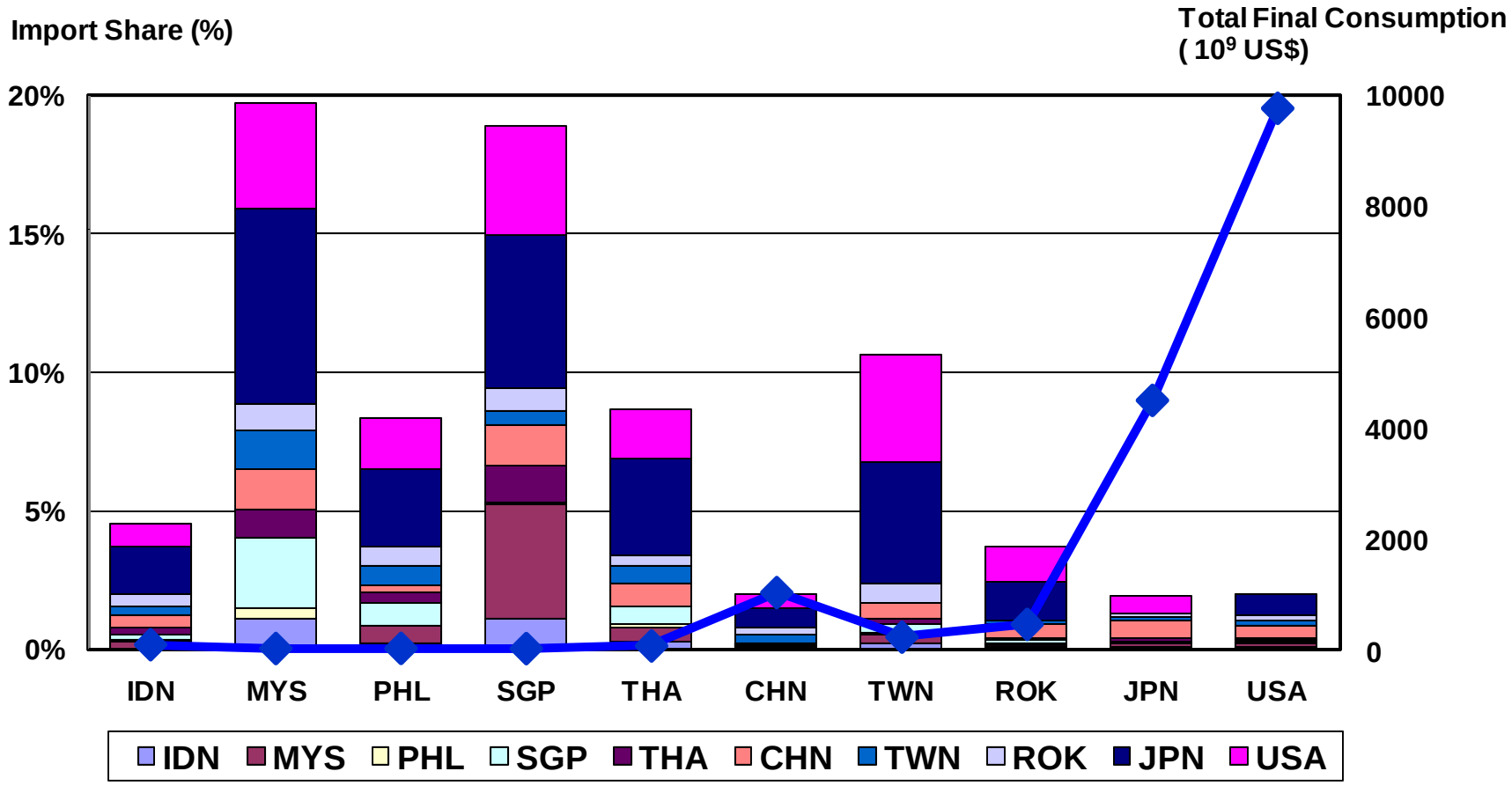
$$cX = \left[c(I-\alpha A)^{-1}\right]\left\{\begin{array}{l}\left[(1-\alpha)\left(Ax+F+E\right)\right] \\ +\alpha F+\alpha E\end{array}\right.$$

Origin and Share of Imports in Intermediate Inputs (2000)



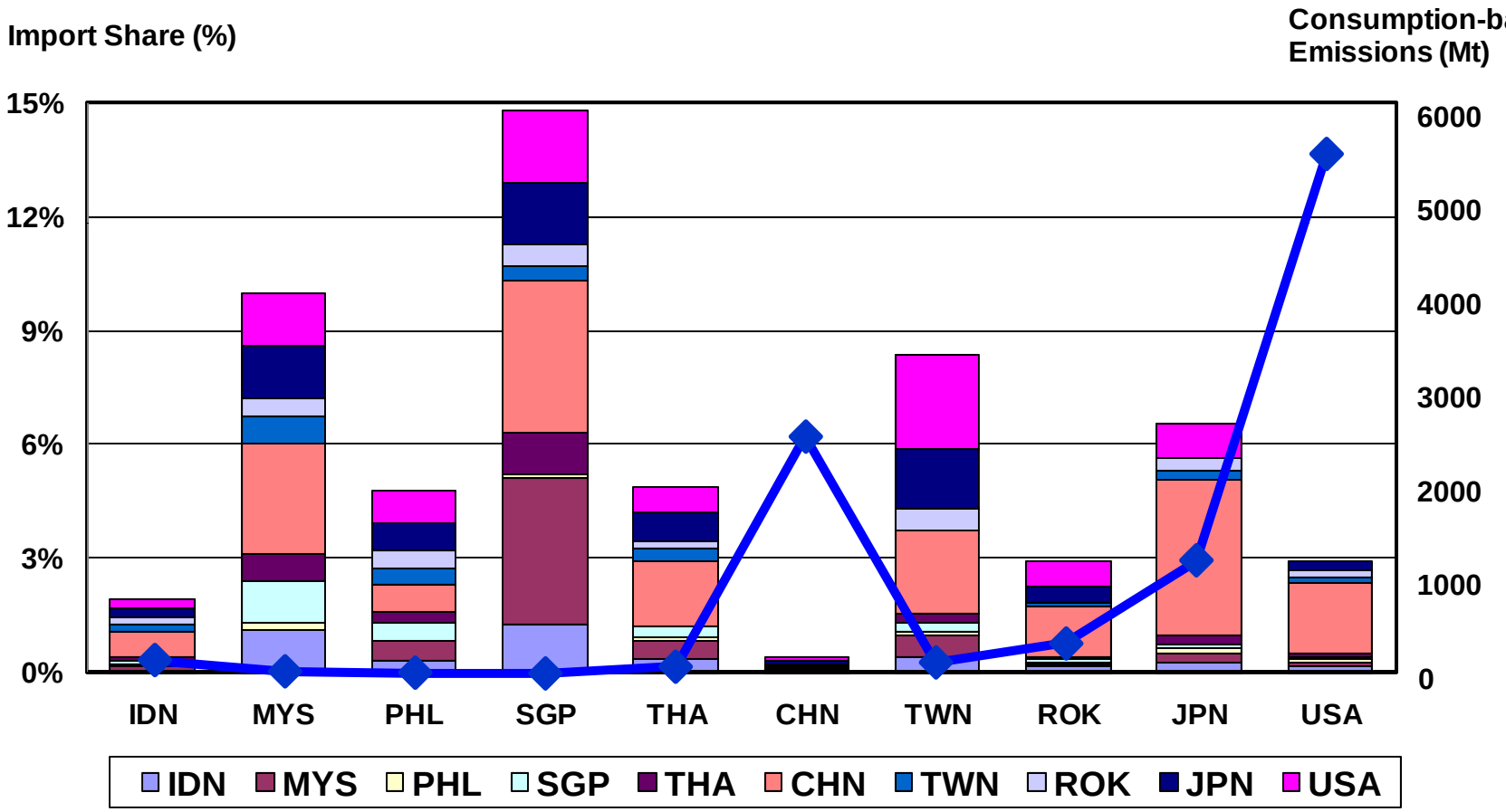
Source: The author complied based on MRIO (IDE-JETRO).

Origin and Share of Imports in Final Consumption (2000)



Source: The author complied based on MRIO (IDE-JETRO).

Origin and Share of Emissions Embodied in Final Consumption - Scheme I (2000)



Source: The author's calculation.

National Responsible Emissions Based on Sch1-MRIO (in Mt-CO_2 2000)

Region	PI_M	P2_M	P3	P4	Consumer responsibility	Producer responsibility	Difference	Difference (%)
IDN	133	4	19	53	209	273	-64	-23%
MYS	47	7	15	15	84	118	-34	-29%
PHL	36	3	9	17	65	69	-4	-6%
SGP	36	7	28	4	75	60	15	25%
THA	92	6	20	21	139	155	-16	-10%
CHN	2,252	9	65	311	2,637	3,176	-539	-17%
TWN	94	14	38	56	202	217	-15	-7%
ROK	267	11	63	88	429	435	-6	-1%
JPN	862	82	155	310	1,409	1,179	230	20%
USA	4,318	163	551	1,105	6,137	5,702	435	8%
Total	8,137	306	963	1,980	11,386	11,384	2	0.02%

National Responsible Emissions Based on Sch1-SRIO (in Mt-CO_2 2000)

Region	PI_S	P2_S	P3	P4	Consumer responsibility	Producer responsibility	Difference	Difference (%)
IDN	128	11	19	53	211	273	-62	-23%
MYS	42	30	15	15	102	118	-16	-14%
PHL	33	11	9	17	70	69	1	2%
SGP	29	24	28	4	85	60	25	42%
THA	84	21	20	21	146	155	-9	-6%
CHN	2,214	68	65	311	2,658	3,176	-518	-16%
TWN	82	47	38	56	223	217	6	3%
ROK	240	47	63	88	438	435	3	1%
JPN	769	107	155	310	1,341	1,179	162	14%
USA	4,205	163	551	1,105	6,024	5,702	322	6%
Total	7,826	528	963	1,980	11,297	11,384	-87	-1%

National Responsible Emissions Based on Sch2-MRIO (in Mt-CO_2 2000)

Region	S1	S2	P3	P4	National emissions	Producer responsibility	Difference	Difference (%)
IDN	131	41	19	53	245	273	-29	-10%
MYS	45	18	15	15	95	118	-23	-20%
PHL	30	12	9	17	68	69	-2	-2%
SGP	29	12	28	4	72	60	12	21%
THA	79	24	20	21	144	155	-10	-7%
CHN	1,891	568	65	311	2,835	3,176	-341	-11%
TWN	86	26	38	56	206	217	-11	-5%
ROK	197	78	63	88	425	435	-10	-2%
JPN	658	193	155	310	1,315	1,179	136	12%
USA	3,097	1,227	551	1,105	5,980	5,702	278	5%
Total	6,243	2,199	963	1,980	11,385	11,384	1	0.01%

Trade Balance of CO_2

Country/ Region	Trade Deficit/Mt CO_2 (Sch1-MRIO)	Trade Deficit/Mt CO_2 (Sch1-SRIO)
IDN	22	63
MYS	20	15
PHL	4	-1
SGP	-2	-25
THA	16	8
CHN	466	566
TWN	14	-4
ROK	21	-1
JPN	-156	-162
USA	-356	-323

Sources and Destinations of Embodied Carbon Based on Sch1-MRIO (in Mt-CO_2 2000)

Region	IDN	MYS	PHL	SGP	THA	CHN	TWN	ROK	JPN	USA	ROW
IDN	133.2	0.8	0.2	0.6	0.4	0.2	0.6	0.4	2.6	6.4	32.4
MYS	0.3	47.2	0.3	1.8	0.6	0.5	0.9	0.4	3.5	6.7	27.8
PHL	0.0	0.1	36.5	0.0	0.1	0.1	0.1	0.1	1.5	4.1	9.3
SGP	0.1	0.8	0.3	35.7	0.3	0.3	0.4	0.3	1.1	2.9	25.6
THA	0.3	0.5	0.2	0.5	91.8	0.3	0.4	0.2	3.1	5.3	31.3
CHN	1.3	2.0	0.4	1.9	2.0	2,252.2	3.6	4.8	51.6	103.6	369.1
TWN	0.3	0.5	0.3	0.2	0.4	2.1	94.4	0.4	3.1	8.3	50.2
ROK	0.3	0.3	0.3	0.3	0.2	1.4	1.0	267.5	4.0	9.8	77.1
JPN	0.5	1.0	0.4	0.8	0.9	1.7	2.6	1.6	861.9	15.4	55.2
USA	0.4	1.0	0.5	0.9	0.8	2.3	4.1	2.6	11.3	4,318.5	333.8
ROW	18.9	15.3	8.9	27.6	20.4	65.1	37.8	62.6	154.8	551.4	

Bilateral Trade Balance of Embodied Carbon Based on Sch1-MRIO (in Mt-CO_2 2000)

Region	IDN	MYS	PHL	SGP	THA	CHN	TWN	ROK	JPN	USA	ROW
IDN	0.0	0.5	0.2	0.5	0.1	-1.1	0.3	0.1	2.1	6.0	13.5
MYS	-0.5	0.0	0.2	1.0	0.1	-1.5	0.4	0.1	2.5	5.7	12.4
PHL	-0.2	-0.2	0.0	-0.3	-0.1	-0.3	-0.2	-0.2	1.1	3.6	0.4
SGP	-0.5	-1.0	0.3	0.0	-0.2	-1.6	0.2	0.0	0.3	2.0	-2.0
THA	-0.1	-0.1	0.1	0.2	0.0	-1.7	0.0	0.0	2.2	4.5	10.9
CHN	1.1	1.5	0.3	1.6	1.7	0.0	1.5	3.4	49.9	101.3	304
TWN	-0.3	-0.4	0.2	-0.2	0.0	-1.5	0.0	-0.6	0.5	4.2	12.4
ROK	-0.1	-0.1	0.2	0.0	0.0	-3.4	0.6	0.0	2.4	7.2	14.5
JPN	-2.1	-2.5	-1.1	-0.3	-2.2	-49.9	-0.5	-2.4	0.0	4.1	-99.6
USA	-6.0	-5.7	-3.6	-2.0	-4.5	-101.3	-4.2	-7.2	-4.1	0.0	-217.6
ROW	-13.5	-12.0	0.0	2.0	-10.9	-304	-12.4	14.0	99.6	217.6	0.0

Ranking of Sectoral Carbon Intensity in Production

(emissions per unit sectoral output)

	IDN	MYS	PHL	SGP	THA	CHN	TWN	ROK	JPN	USA
S1	9	7	8	10	6	5	3	2	4	1
S2	7	9	8	10	4	6	2	1	5	3
S3	5	9	8	10	3	2	7	1	6	4
S4	2	9	3	10	7	4	1	6	5	8
S5	4	8	7	9	2	6	10	1	3	5
S6	4	10	2	1	9	5	3	7	8	6
S7	3	1	4	9	8	2	6	5	7	10
S8	7	3	6	10	5	2	1	4	9	8
S9	3	4	5	10	8	7	1	2	6	9
S10	7	3	6	10	5	2	8	1	9	4
S11	3	4	1	10	6	5	7	2	9	8
S12	1	8	6	9	2	3	4	7	10	5
S13	2	1	5	8	6	4	7	10	9	3
S14	1	8	6	9	2	3	4	7	10	5
S15	1	8	2	10	4	3	6	5	9	7
S16	1	5	8	10	4	2	3	9	7	6
S17	2	3	10	9	5	1	4	6	8	7
S18	6	2	10	8	7	1	5	3	9	4
S19	1	3	10	9	4	8	5	2	6	7
S20	3	5	8	1	6	2	7	9	10	4
S21	2	1	3	10	6	7	4	5	8	9
S22	1	4	3	10	5	7	6	2	9	8
S23	4	7	2	10	9	3	6	1	5	8
S24	5	7	4	10	9	1	6	2	3	8

First; Second; Third.

- Lower sectoral carbon intensity: Japan, USA and Singapore;
- Higher sectoral carbon intensity: Indonesia, ROK, China and Taiwan.

Ranking of Sectoral Carbon Intensity in Consumption

(emissions per unit final consumption)

	IDN	MYS	PHL	SGP	THA	CHN	TWN	ROK	JPN	USA
S1	8	5	9	10	6	1	4	3	7	2
S2	9	7	10	6	5	1	4	3	8	2
S3	7	4	9	6	5	2	8	1	10	3
S4	3	6	4	10	9	1	2	7	5	8
S5	5	7	9	6	2	4	10	1	3	8
S6	5	10	2	1	8	3	4	7	9	6
S7	4	2	5	3	7	1	8	6	10	9
S8	5	2	9	7	4	1	6	3	10	8
S9	2	4	7	8	5	1	3	6	10	9
S10	2	3	6	5	7	1	9	4	10	8
S11	2	3	4	9	6	1	7	5	10	8
S12	2	4	7	6	3	1	5	9	10	8
S13	2	1	9	5	7	3	6	8	10	4
S14	2	5	8	6	3	1	4	9	10	7
S15	1	5	3	9	4	2	7	6	10	8
S16	2	4	6	7	5	1	3	8	10	9
S17	2	4	8	5	3	1	6	7	10	9
S18	2	4	3	6	7	1	8	5	10	9
S19	2	3	8	6	5	1	7	4	10	9
S20	3	6	7	1	5	2	8	9	10	4
S21	2	3	6	8	4	1	5	7	10	9
S22	1	5	3	10	6	2	7	4	9	8
S23	2	5	6	4	3	1	9	7	10	8
S24	2	4	8	5	3	1	10	6	9	7

First; Second; Third.

- Lower sectoral carbon multiplier: Japan, Taiwan, USA and Singapore;
- Higher sectoral carbon multiplier: China, Indonesia and Malaysia.

Conclusions

- Carbon embodied in multilateral trade is significant, e.g. about 1,269 (or 1,491) Mt-CO_2 or 11% (13%) of total national responsible emissions of ten economies embodied in multilateral trade based on Sch1-MRIO (Sch1-SRIO). At national level, it could be high up to 47% (61%) in case of Singapore.
- The results indicate national emission accounting and therefore national responsibility is sensitive to methodology adopted. For example, responsibility allocated based on producer responsibility and consumer responsibility could cause change in national inventory from –539 to 435 Mt-CO_2. Even based on the same consumer responsibility, national emission account could be varied from using MRIO to using SRIO for estimation.

Conclusions

- Carbon leakage is happening in a non negligible way from developed economies to developing economies. This could offset the efforts made to achieving the mitigation target and has yet been properly considered by the UNFCCC. To address this issue, trade adjustment to current national accounting could be a option among others, such as extending the participation of non-Annex I countries in binding reduction and Border Tax Adjustment, etc.

- In allocating the responsibility associated with emissions embodied in international trade, full producer responsibility and full consumer responsibility are two extremes. Shared producer and consumer responsibility lie between them and could work to address both actors. In this paper, the ratio of added value in total external inputs is used for defining shares. However, this is only one of alternative ratios. This could also be determined through negotiations between trading partners for example.

Thank you very much for your attention!

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