

# Which Social Cost of Carbon? A Theoretical Perspective

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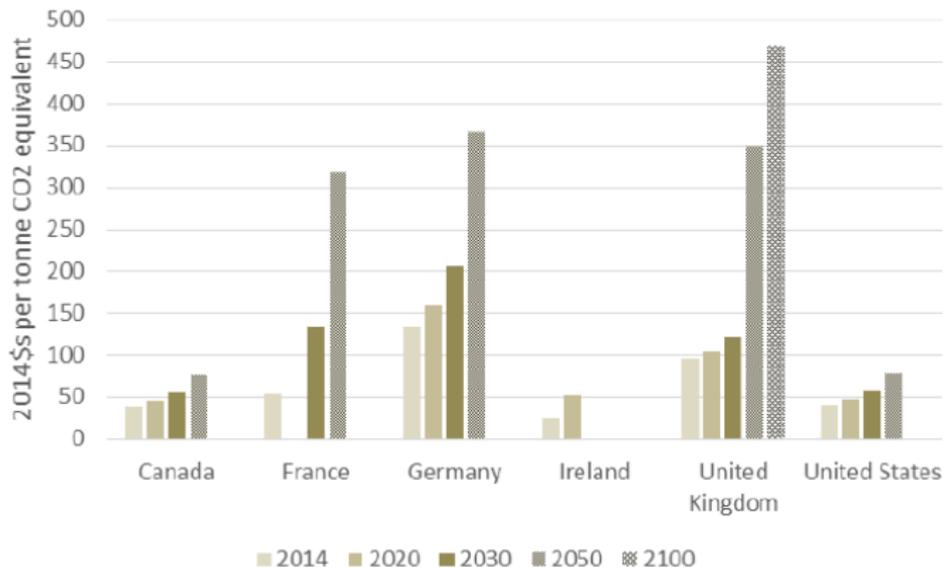
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# Social Cost of Carbon (SCC) and Policy Analysis

- The problem of climate change is the problem of a global externality
- The SCC reflects the monetized, marginal damages of emissions over *all space and time*
- Many countries are beginning to account for the SCC in regulatory impact analysis
  - United States, Canada, Finland, France, Germany, Italy, Mexico, Netherlands, Norway, United Kingdom
  - Example: US EPA's Clean Power Plan climate benefits of \$20 billion/year by 2030

# SCC used for *ex ante* CBA

Selected countries (source OECD 2015)



# Growing Debate About the Use of the Global SCC

- Countries are accounting for *global* benefits in CBA of *domestic* policies
- Advocates for use of the Global SCC
  - A unique global problem
  - Necessary for globally efficient emissions
  - International relations and the need for coordination
  - IWG (2010), Greenstone *et al.* (2013), Pizer *et al.* (2014)
- Critics supporting use of the Domestic SCC
  - Domestic SCC has a firmer legal foundation
  - Global SCC will result in domestic resource misallocation
  - Violates individual rationality
  - Dudley & Mannix (2014), Gayer & Viscusi (2015), Darmstadter (2016), Fraas *et al.* (2016)

# Motivation for this Research

- During the Obama years
  - Concerns about political implications of discussion about global v. domestic SCC
  - Cognitive dissonance (or lack of awareness) in the economics profession about individual rationality of applying the Global SCC
- With the Trump Administration
  - Announcement expected tomorrow to begin rolling back the CPP
  - Poised to challenge the SCC based on the assumed discount rate and global focus
- Research on the SCC is almost entirely empirically based, using integrated assessment models (IAMs)
- A needed theoretical foundation for the SCC and what to internalize

# Research Objectives

- ① Place the SCC in the context of a global public bad among countries
  - ① Highlighting efficiency and distributional concerns
  - ② Provide some empirical evidence
- ② How can countries rationalize internalization of the Global SCC?
  - ① Conjectural variations
  - ② Repeated games
- ③ In what ways can we expect agreement on the value of the Global SCC among countries
  - ① Preference aggregation
  - ② Provide some empirical evidence
- ④ General contribution: the SCC is not simply an application of estimating and internalizing an externality among sovereign nations

# Model Setup

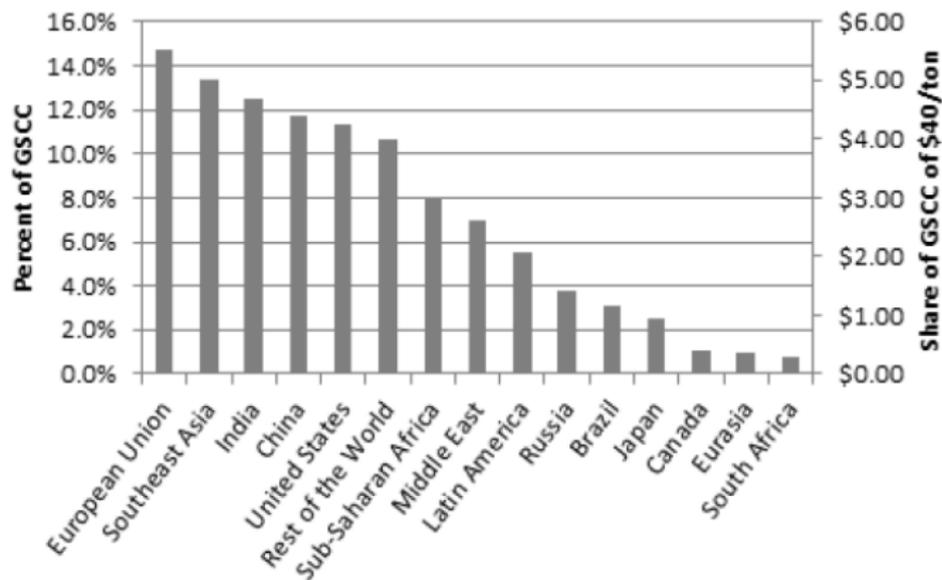
- Countries  $i = 1, \dots, n \geq 2$
- Country  $i$  emissions  $x_i$
- Aggregate emissions  $X = \sum_{i=1}^n x_i = x_i + X_{-i}$
- Damages in country  $i$  are  $D_i(X) = \alpha_i X$ , where  $\alpha_i > 0$
- Benefits in country  $i$  are  $B_i(x_i)$ , where  $B_i' > 0$  and  $B_i'' < 0$
- Country  $i$ 's demand for emissions  $x_i(p_i) = \{x_i : B_i'(x_i) = p_i\}$
- Observation: externality (agents) vs. global public bad (countries)

# Two Social Costs of Carbon

- The Domestic Social Cost of Carbon (DSCC) is  $\alpha_i$  for all  $i$ .
- The Global Social Cost of Carbon (GSCC) is  $A = \sum_{i=1}^n \alpha_i$ .

# The Distribution of DSCCs for a GSCC of \$40

Based on averaging assumptions across 3 IAMs in Nordhaus (2015)



# Globally Efficient Emissions

- Consider the shadow value of emissions  $s_i$  to internalize in each country to account for quantity- and price-based policies
- Pareto optimal emissions must satisfy

$$\max_{s_1, \dots, s_n} \sum_{i=1}^n B_i(x_i(s_i)) - A \sum_{i=1}^n x_i(s_i)$$

- The solution can be written

$$B'_1(x_1(s_1^*)) = \dots = B'_n(x_n(s_n^*)) = A$$

- Key result is that  $s_i^* = A$  (i.e., the GSCC) for all  $i$

# Equilibrium Emissions

- Each country solves

$$\max_{s_i} B_i(x_i(s_i)) - \alpha_i [x_i(s_i) + X_{-i}]$$

- The solution will satisfy

$$B'_i(x_i(\hat{s}_i)) = \alpha_i \text{ for all } i$$

- Key result is that  $\hat{s}_i = \alpha_i$  (i.e., the DSCC) for all  $i$
- Equilibrium emissions are inefficiently high

$$\hat{s}_i < s_i^* \implies \hat{x}_i > x_i^* \implies \hat{X} > X^*$$

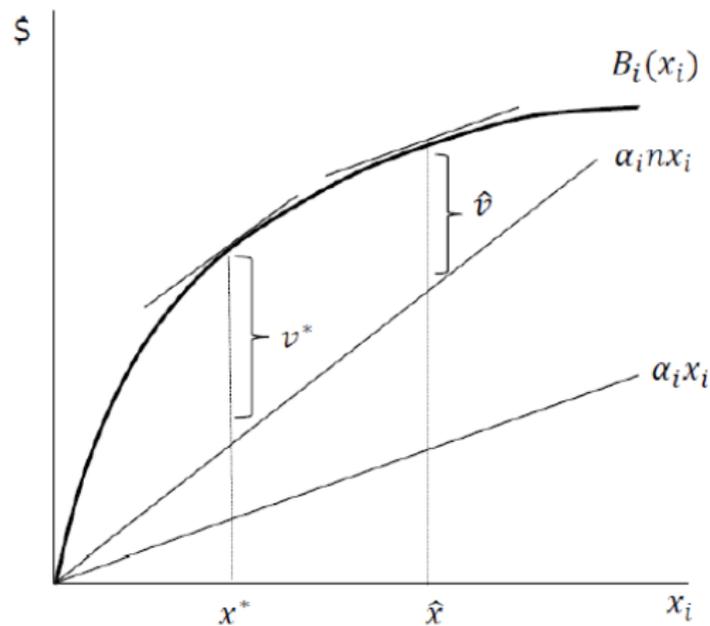
# Free Riding

		Country A	
		DSCC <sub>A</sub>	GSCC
Country B	DSCC <sub>B</sub>	2, 2	4, 1
	GSCC	1, 4	3, 3

# Free Riding with Distributional Concerns

		Country A	
		DSCC <sub>A</sub>	GSCC
Country B	DSCC <sub>B</sub>	3 , 1	5 , 0
	GSCC	0 , 5	2 , 4

# Identical Countries: Always a Pareto Improvement



# Distribution with Heterogenous Countries

- Welfare change for country  $i$  with move to efficient emissions

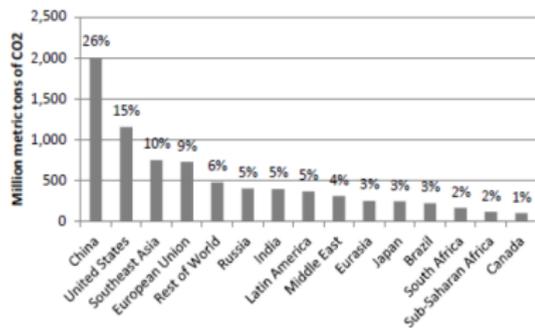
$$v_i^* - \hat{v}_i = \underbrace{\alpha_i(\hat{X}_{-i} - X_{-i}^*)}_{>0} + \underbrace{\alpha_i(\hat{x}_i - x_i^*) - \int_{x_i^*}^{\hat{x}_i} B'_i(z) dz}_{<0}$$

- There is a potential Pareto improvement:
  - $\sum_{i=1}^n v_i^* > \sum_{i=1}^n \hat{v}_i$  even if not  $v_i^* > \hat{v}_i$  for all  $i$
- Transfers and climate finance:
  - there exists  $(\tau_1, \dots, \tau_n)$  where  $\sum_{i=1}^n \tau_i = 0$  and  $v_i^* - \hat{v}_i + \tau_i \geq 0$  for all  $i$

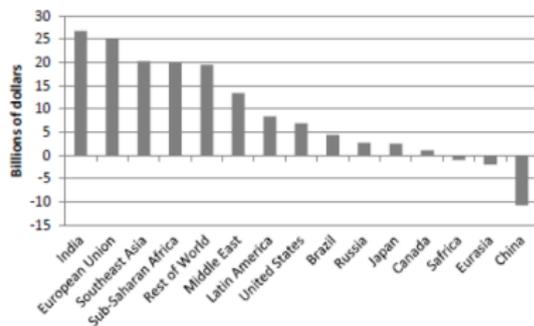
# Empirical Evidence on Distributional Consequences

Based on a modified C-DICE model (Nordhaus 2015)

Abatement:  $\hat{x}_i - x_i^*$

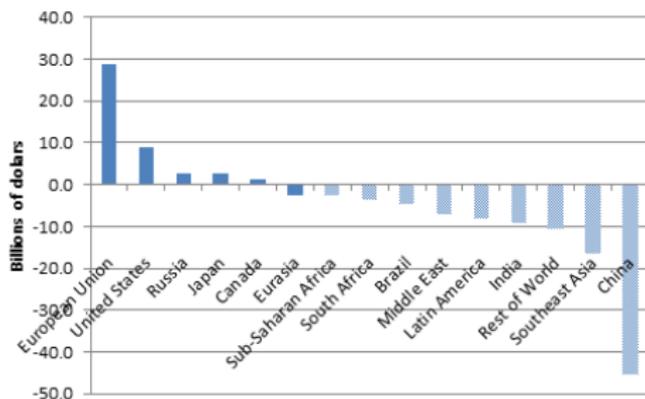


Change in welfare:  $v_i^* - \hat{v}_i$



# (Aside) Alternative Interpretations of Transfers

- Rather than  $v_i^* - \hat{v}_i + \tau_i \geq 0$  for all  $i$ , what if
  - Compensation for foregone development:  $\int_{x_i^*}^{\hat{x}_i} B_i'(z) dz$
  - “Loss-and-damage”:  $\alpha_i X_{-i}$
- Possible compensation for forgone development among non-Annex 1 countries



# Rationalizing Internalization of the GSCC?

Two approaches:

- ① One-shot conjectures
  - ② Repeated game setup (Folk Theorems)
- To simplify notation, I consider choices over  $x_i$  rather than  $s_i$

# A Conjectures Rationalization for the GSCC

- Country  $i$  conjectures that  $dX_{-i}/dx_i = \gamma_i > 0$
- This implies  $X_{-i} = \gamma_i x_i + \kappa$
- Country  $i$ 's choice of  $x_i$  will satisfy  $B'_i(x_i) = \alpha_i(1 + \gamma_i)$
- Hence  $x_i = x_i^*$  if  $\gamma_i = A_{-i}/\alpha_i$  (an effective subsidy)
- Isomorphic to Lindahl and optimal burden sharing equilibria
- Concerns with conjectural variations approach
  - Arbitrary
  - Implicitly a repeated game

# Convert to a Repeated Game

- Game is infinitely repeated or of uncertain duration
- Consider only pure and stationary strategies with discount factor  $\delta \in (0, 1)$
- Nash equilibrium (NE) in the stage game,  $(\hat{x}_1, \dots, \hat{x}_n)$ , is a subgame perfect Nash equilibrium (SPNE) in the repeated game
- To what extent does repeated play allow other NE to emerge as a SPNE?

# Nash Reversion (Folk Theorem)

- A strategy profile where all countries play  $(x_1, \dots, x_n)$  until any one country deviates, then all play  $(\hat{x}_1, \dots, \hat{x}_n)$  thereafter
- For any  $(x_1, \dots, x_n)$  such that  $v_i(x_i, \mathbf{x}_{-i}) \geq v_i(\hat{x}_i, \hat{\mathbf{x}}_{-i})$  for all  $i$ , there exists a  $\underline{\delta} < 1$  such that for all  $\delta > \underline{\delta}$ , infinite repetition of the strategy is a SPNE

# Repeated Game Results

- Internalizing the GSCC is individually rational
  - If the discount rate is sufficiently low and moving to efficient emissions is a Pareto improvement
  - If the discount rate is sufficiently low and transfers are possible
- Important features of theory and COP21 agreement
  - Repeated interaction
  - Complete information
  - Use of transfers
- Further extensions building on the Folk Theorem literature
  - Alternative punishment schemes (e.g., climate clubs)
  - Imperfect monitoring (public and private)

# Country Preferences for a Global Shadow Price

- The GSCC is an objective parameter in theory (except for choice of discount rate)
- Among sovereign countries, the preferred realization is subjective
- Heterogenous countries will have differing views, even with an objective estimate of the GSCC and DSCCs
- A problem of preference aggregation
  - Weitzman (2014, 2015): What uniform carbon tax would a World Climate Assembly choose?
  - The World Bank: Which SCC should be used to evaluate projects?

# Defining Preferences for a Global Shadow Price

- Let  $s$  denote the minimum shadow value on emissions that all countries internalize
- Each country's associated level of emissions is

$$x_i(s) = \left\{ \begin{array}{ll} x_i : B'_i(x_i) = s & \text{if } s \geq \alpha_i \\ x_i : B'_i(x_i) = \alpha_i & \text{otherwise} \end{array} \right\}$$

- Each country solves

$$\max_{s_i} B_i(x_i(s_i)) - \alpha_i \sum_{j=1}^n x_j(s_j)$$

# The Strategic Social Cost of Carbon (SSCC)

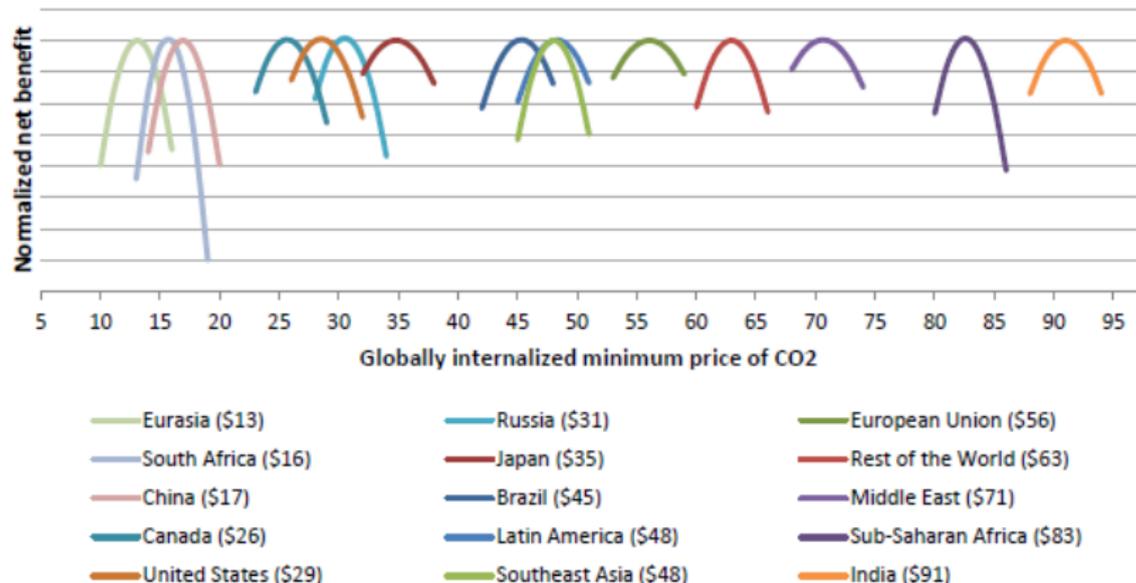
- The SSCC will solve

$$B'_i(x_i(s_i)) = \alpha_i + \frac{\alpha_i}{x'_i(s_i)} \sum_{j \neq i} x'_j(s_i)$$

- Relation to previous work
  - Weitzman (2014, 2015)
  - Earlier provenance in Bowen (1943)
- A key result:  $DSSC_i < SSCC_i \begin{matrix} \leq \\ \geq \end{matrix} GSCC$

# Single Peaked Preferences for the SSCC

Given a GSCC of \$40 and a modified C-DICE model



# Decision Rules and Corresponding Results

Outcome is the “Decision Cost of Carbon” (DCC)

Decision rule	Outcome DCC	Mean SSCC
Majority voting	\$45	\$44.8
Population weighted	\$51	\$54.6
GDP weighted	\$46	\$45.3
Unanimity (Nash reference)	\$21	
World Bank voting shares		
Intl Bank for Reconstruction and Devt (IBRD)	\$48	\$46.5
Intl Finance Corporation (IFC)	\$46	\$45.7
Intl Development Association (IDA)	\$54	\$50.2

# Concluding Thoughts

- Modeling emissions as a global public bad among countries frames the current debate about the SCC
  - Global or domestic?
  - Pareto optimality or equilibrium?
  - Distributional concerns and transfers?
- With extensions, choosing the GSCC can be individually rational
  - Some conditions match what we are seeing internationally
  - More work on repeated games would be fruitful
  - Lessons from the “arms race”?
- GSCC estimates are in principle the result of positive analysis
- But the normative implications among sovereign countries are not a straightforward application of internalizing external costs
- A first step towards more theoretical work on the questions of the GSCC, the DSCC, the SSCC, or something else