Overlapping International Environmental R&D Agreements with Transaction Costs

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International Environmental Agreements

- Paris Agreement (2015) goals: Carbon Capture and Storage (CCS) is very likely necessary to achieve these goals (see, e.g., "The Global Status of CCS: 2017").
- CCS has tremendous potential to reduce global carbon emissions (de Coninck et al. 2009).
- Nations that are heavily dependent on energy from fossil fuels are forming international partnerships to share these efforts.

International Green R&D Agreements

- Australia, Canada, China, EU, India, Japan, Korea, Norway, South Africa, UK and USA are forming international partnerships to share efforts to further develop and deploy CCS.

- The technology requires the financing of very large upfront costs, regulatory incentives, research, development and demonstration and solutions to logistic and storage issues.

China has bilateral agreements with Australia, Japan, the USA, the EU, and a multilateral agreement with the EU and Norway (Hagemann et al. 2011).

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China and the EU are hubs in the international CCS network, since they have entered into several bilateral and multilateral international agreements.

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Bilateral agreements, hub-and-spoke agreements, multilateral agreements: which type of network is desirable, stable?

A large research network may enable a nation to have access to new as well as to complementary pieces of knowledge and reduce the likelihoods of inertia and redundancy in its R&D processes.

The amount of R&D spillovers enjoyed by a nation may significantly increase as it forms new bridges across nations.

Creative ideas may emerge from combination of various pieces of knowledge in original and useful ways, and the expansion of a research network is known to produce more knowledge.

However, in the case of CCS, there appear to be important factors that limit the efficient size of the international research network.

The inherent interdependency of the various research tasks in CCS (carbon capture, logistics and storage) implies that research teams need to be very cohesive in order to solve the intertwined complex problems that they face.

In cohesive research teams, collaborators trust each other and effectively cooperate in knowledge creation.

Trust among research collaborators builds slowly because researchers give preference to past and existing relationships to engaging in new collaborations.

Researchers who contemplate new collaborations face substantial informational asymmetries with respect to each other's skills, expertise and research effort.

The existence of informational asymmetries may reduce the impetus for continual expansion of research networks brought up by R&D sharing.

We consider the benefits and costs associated with production of green R&D by international research collaborators in order to examine the efficiency and stability of international green R&D agreements.

Main Benefit: Ceteris paribus, knowledge sharing increases the amount of knowledge.

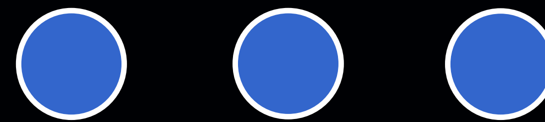
Main Cost: Relational attrition, arising from weak ties among collaborators, lead to efficiency losses.

Agreement Structures

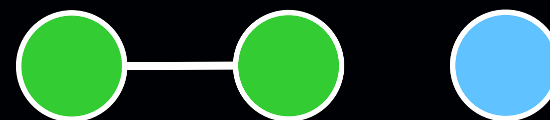
- Suppose {1, 2, 3} denotes the set of 3 players, then the subset of { {1}, {2}, {3} } is the "singleton" structure.
- The subsets of { {1, 2}, {3} }, { {1, 3}, {2} }, and { {1}, {2, 3} } are "isolated bilateral" agreements.
- The subsets of { {1, 2}, {1, 3} }, { {1, 2}, {2, 3} }, and { {1, 3}, {2, 3} } denote "hub-and-spoke" or "overlapping" coalitions.
- The subset of { {1, 2, 3} } is the "multilateral" coalition.

Agreement Structures

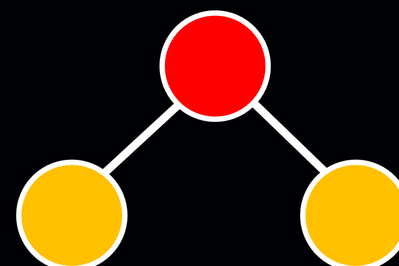
- Singleton:



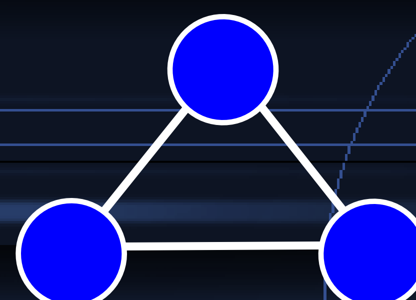
- Isolated Bilateral:



- Hub-and-Spoke:



- Multilateral:



Positive Externalities, Coalition-Proof

- We examine formation of international agreements where green R&D provision produces two types of positive externalities; a global public good (reduction of carbon dioxide emissions) and spillovers in technological agreements.
- We utilize the Coalition Proof Nash Equilibrium (CPNE) concept to refine the Nash equilibria and identify stable coalitional structures.

Related literature

- Mukunoki and Tachi (2006)

  They show that hub-and-spoke networks are likely to be more effective in delivering multilateral free trade in a sequential model of free trade agreements.

- Silva and Zhu (2013)

  They show that the concept of CPNE advanced by Bernheim et al. (1987) can be extended to a setting in which coalitions may overlap.

Related Literature

- Barrett (1994); Diamantoudi and Sartzetakis (2006, 2015); Golombek and Hoel (2011); Silva (2017) – IEAs;
- Furusawa and Konishi (2005, 2007, 2011) – Coalition Proofness; Applications to Public Goods;
- Jackson and Wollinsky (1998); Bloch and Jackson (2007) – Social Networks.

The Basic Model (Singleton)

- Nation i = 1, 2, 3, solves the problem:

$$\max_{q_i} u_i(x_i, Q) = x_i + v(Q), \quad s.t. \quad x_i + c(q_i) = I$$

x_i : the numeraire good, q_i: R&D provision,

$Q = \sum_{i=1}^{3} q_i$: the public good (reduction in global CO_2),

$$v''(\cdot) < 0 < v'(\cdot),\ c'(\cdot) > 0, c''(\cdot) > 0.$$

- The Nash equilibrium is characterized by

$$v'(Q) = c'(q_i),\ i = 1, 2, 3.$$

International R&D Collaboration

Benefits:

Interaction with another nation creates new ideas, which allow nations to become more productive in green R&D activities.

Transaction Costs:

– Coordination cost depends on the number of partners.

– Relational attrition cost (e.g., communication barriers, moral hazard and adverse selection issues, etc)

International R&D Collaboration

- If nation i collaborates with $n-1$ nations, nation i' s provision of R&D is:

Actual R&D: $$g_i = e(a, n-1)\left(q_i + \frac{1}{n}\sum_{j \neq i} g_j\right)$$

Alternatively: $$q_i = e(a, n-1)^{-1} g_i - \frac{1}{n}\sum_{j \neq i} g_j$$

$e(a, n-1)$: Efficiency rate, $a \in [0,1]$: Attrition rate,

$$e(0, n-1) = e(a, 0) = 1, \quad \frac{de}{da} < 0, \quad \frac{de}{d(n-1)} < 0.$$

Isolated Bilateral Agreement

- If nations 1 and 2 engage in a bilateral green R&D agreement and nation 3 stands alone, the Nash equilibrium is characterized by

$$v'(G) = c'\left(e^{-1}(a,1)g_1 - \frac{g_2}{2}\right)e^{-1}(a,1),$$

$$v'(G) = c'\left(e^{-1}(a,1)g_2 - \frac{g_1}{2}\right)e^{-1}(a,1),$$

$$v'(G) = c'(g_3).$$

Proposition 1

- As the attrition rate increases, the R&D of nation 3 increases, while the R&D of each nation $i = 1, 2$ decreases,

$$\frac{dg_3^P}{da} > 0 \text{ and } \frac{dg_i^P}{da} < 0,$$

R&D products of nation i and nation 3 are strategic substitutes.

Proposition 2

- For all $a > 0$, each collaborator's welfare is higher than the stand-alone nation's welfare.

$$u_1^P = u_2^P \geq u_3^P \text{ since } q_3^P \geq q_i^P \text{ for } a \geq 0,$$

$$\text{where } u_i^P = I + v\left(G^P\right) - c\left(q_i^P\right), \; i = 1, 2,$$

$$u_3^P = I + v\left(G^P\right) - c\left(q_3^P\right).$$

Hub-and-Spoke Coalition

- If nation 1 has bilateral green R&D agreements with nations 2 and 3, the Nash equilibrium is characterized by

$$v'(G) = c'\left(e^{-1}(a,2)g_1 - \frac{g_2+g_3}{3}\right)e^{-1}(a,2),$$

$$v'(G) = c'\left(e^{-1}(a,1)g_2 - \frac{g_1}{2}\right)e^{-1}(a,1),$$

$$v'(G) = c'\left(e^{-1}(a,1)g_3 - \frac{g_1}{2}\right)e^{-1}(a,1).$$

Proposition 3

- For all $a > 0$, the hub's welfare is higher than each spoke's welfare.

$$u_1^H > u_2^H = u_3^H \text{ since } q_1^H < q_2^H = q_3^H$$

$$\text{where } u_1^H = I + v\left(G^H\right) - c\left(q_1^H\right),$$

$$u_i^H = I + v\left(G^H\right) - c\left(q_i^H\right),\ i = 2, 3.$$

Multilateral Coalition

- If each nation has bilateral agreements with the other nations, the Nash equilibrium is characterized by

$$v'(G) = c'\left(e^{-1}(a,2)g_1 - \frac{g_2+g_3}{3}\right)e^{-1}(a,2),$$

$$v'(G) = c'\left(e^{-1}(a,2)g_2 - \frac{g_1+g_3}{3}\right)e^{-1}(a,2),$$

$$v'(G) = c'\left(e^{-1}(a,2)g_3 - \frac{g_1+g_2}{3}\right)e^{-1}(a,2).$$

Coalition Formation

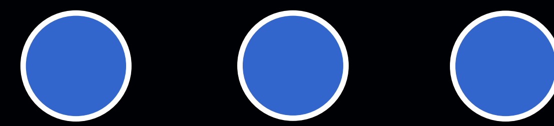
- Multistage game: Assume that nations can have unlimited communication and establish non-binding agreements in the first stage of the game.
- Assume the following functional forms:

$$e(a, n-1) = \left[1 + a(n-1)\right]^{-1},$$

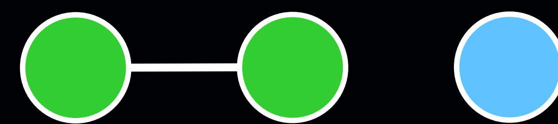
$$v(G) = G\left(1 - \frac{G}{2}\right), \text{ and } c(q_i) = \frac{q_i^2}{2}.$$

Agreement Structures (Again)

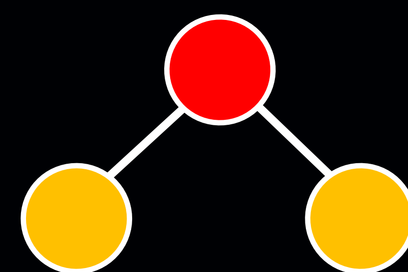
- Singleton:



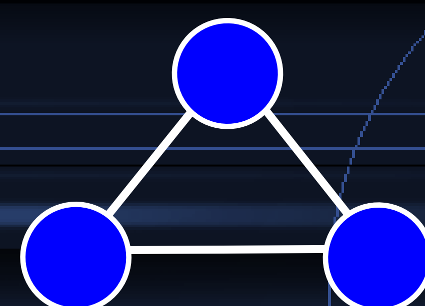
- Isolated Bilateral:

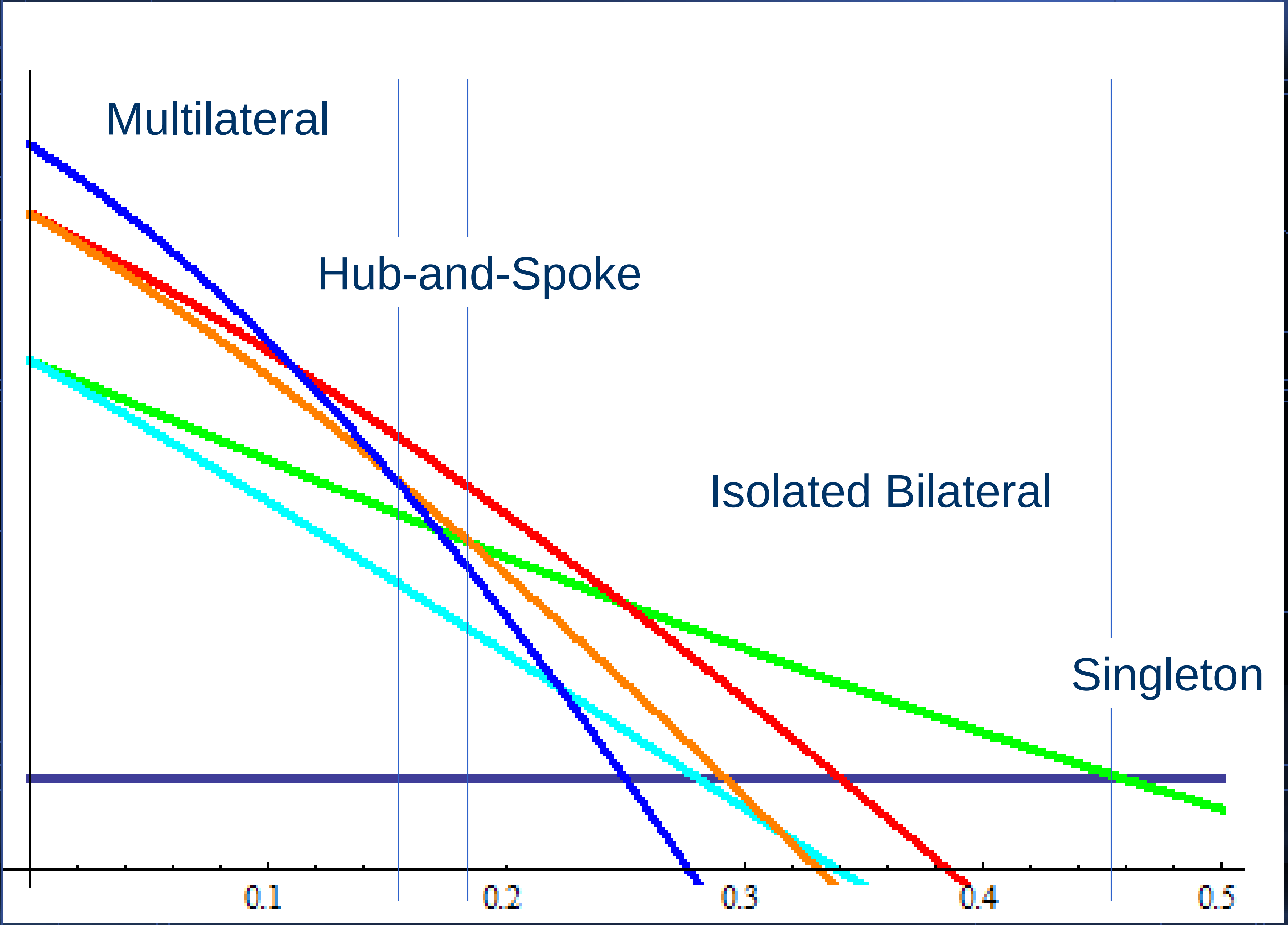


- Hub-and-Spoke:



- Multilateral:





Multilateral
Hub-and-Spoke
Isolated Bilateral
Singleton
0.1
0.2
0.3
0.4
0.5

Proposition 4

- For $0 \leq a < 0.152$, the CPNE is the Nash equilibrium for the multilateral arrangement.
- For $0.152 < a < 0.185$, the CPNE is the Nash equilibrium for the hub-and-spoke arrangement.
- For $0.185 < a < 0.459$, the CPNE is the Nash equilibrium for an isolated bilateral arrangement.
- For $0.459 < a \leq 1$, the CPNE is the Nash equilibrium for the singleton arrangement.

Income Transfers Allowed

- Suppose that an international arbitrator promotes intra-coalition income transfers after observing the R&D contributions of members. The optimization problem in the 3rd stage is:

$$\max_{t_i} \prod_h \left[I + t_h + v(G) - c(q_h) - \bar{u} \right]$$

$$s.t. \quad \sum_h t_h = 0$$

t_i : nation i's monetary transfer received.

Transfer Scheme

- The optimization conditions in the 3rd stage satisfy:

$$u_i = u_j,\ i \neq j, \ \text{ and } \ \sum_h t_h = 0.$$

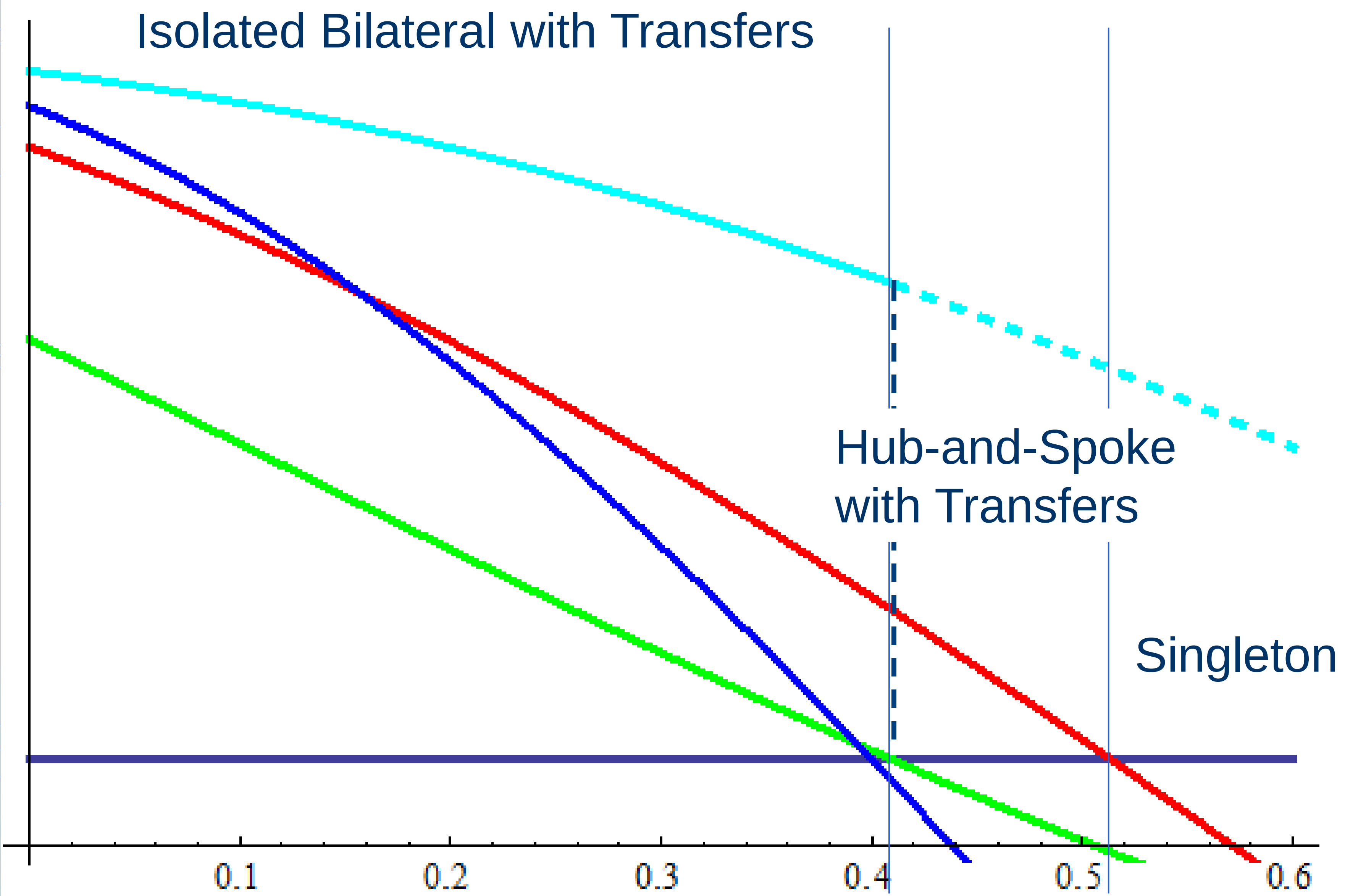
- These yield the intra-coalitional transfers as functions of each member's R&D contribution:

$$t_i = t_i\left(g_i, g_j\right)$$

- Each nation chooses R&D in the 2nd stage.

Proposition 5

- In the subgame perfect equilibrium for the hub-and-spoke setting with transfers, there is no payoff premium for the hub relative to the common payoff earned by the spokes.


Isolated Bilateral with Transfers
Hub-and-Spoke
with Transfers
Singleton
0.1
0.2
0.3
0.4
0.5
0.6

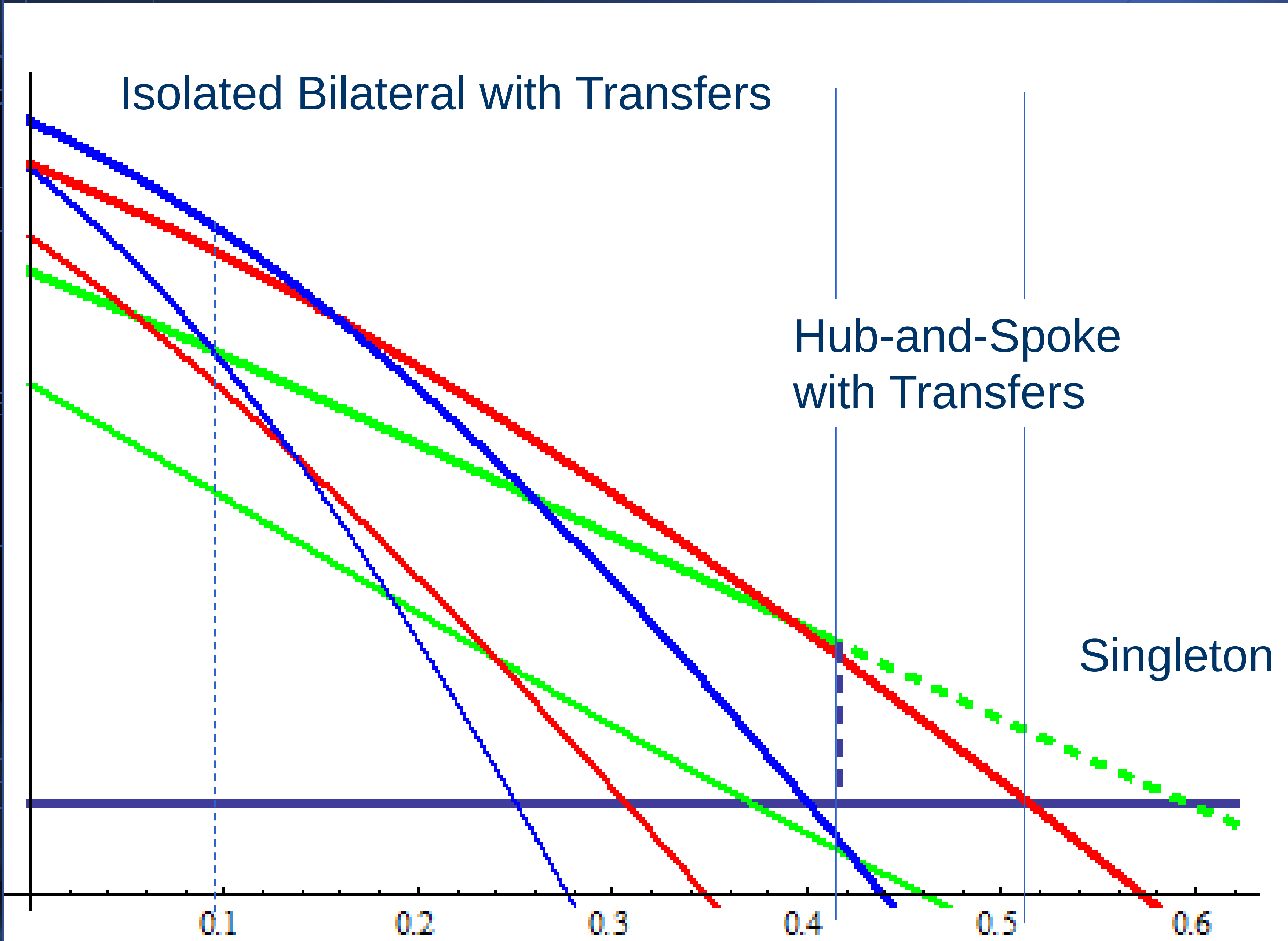
Proposition 6

- For $0 \le a < 0.41$, the CPNE is the Nash equilibrium for the setting in which there is an isolated bilateral agreement.
- For $0.41 < a < 0.514$, the CPNE is the Nash equilibrium for the hub-and-spoke arrangement.
- For $0.514 < a \le 1$, the CPNE is the Nash equilibrium for the setting in which all nations stand alone in R&D production.

Global Welfare

- Suppose that global welfare is the sum of all nations' payoffs:

$$\text{Global Welfare} \equiv \sum_{i=1}^{3} u_i^C$$


Isolated Bilateral with Transfers
Hub-and-Spoke
with Transfers
Singleton
0.1
0.2
0.3
0.4
0.5
0.6

Proposition 7

- For sufficiently small attrition rates, constrained global welfare levels improve when green R&D agreements prohibit transfers.

Larger Economies

- Suppose that $N = \{1,2,3,\ldots,Z\}$ nations, where Z is no less than 4.
- Let $Z - D$ denote the number of nations that collaborate in green R&D agreements by being members of hub-and-spoke or multilateral agreements, where D is the number of stand-alone nations.

Transfers Allowed

If $a = 0$, the stable (single) coalitions are

1. $N = 3, 4, 5, 6$: $Z - D = 2$;
2. $N = 7, \ldots, 13$: $Z - D = 3$;
3. $N = 14, \ldots, 23$: $Z - D = 4$;
4. $N = 24, \ldots, 36$: $Z - D = 5$;
5. $N = 37, \ldots, 51$: $Z - D = 6$;
6. $N = 52, \ldots, 70$: $Z - D = 7$;
7. $N = 71, \ldots, 91$: $Z - D = 8$;
8. $N = 92, \ldots, 115$: $Z - D = 9$;
9. $N = 116, .., 142$: $Z - D = 10$;
10. $N = 143, .., 172$: $Z - D = 11$;
11. $N = 173, .., 204$: $Z - D = 12$.

Proposition 8

- If there is no attrition cost (i.e., $a = 0$), the larger the global economy is, the larger will be the stable multilateral agreement.
- If attrition is costly (i.e., $a > 0$), a hub-and-spoke partial agreement is more likely to prevail as the economy becomes larger.

Large Economies Without Transfers

If income transfers are not allowed within coalitions, the number and types of CPNE increase because there are several Nash equilibria with asymmetric outcomes.

The stable coalition structures can be very large, encompassing all nations in globe – there are multiple types of stable coalition structures depending on the value of the attrition parameter.

Attrition Ranges for the Top 3 PCPNEs

Z	Multilateral	2nd Formation	3rd Formation
4	0 ~ .0691	Circle of 4 (~ .1319)	2 Bilateral (~ .3659)
5	0 ~ .0442	Hub & Circle of 4 (~ .0626)	Circle of 5 (~ .1751)
6	0 ~ .0290	Circle of 6 + 6 Bilateral (~ .0425)	Circle of 6 + 3 Bilateral (~ .0687)

Stable Agreements; Cut-off Attrition Values

Z	2nd Formation	Cut-off value
4	Circle of 4	0.0690696
5	Hub & Circle of 4	0.0441995
6	Circle of 6 + 6 Bilateral	0.0290215
7	H&C of 6 + 6 Bilateral	0.0214552
8	Circle of 8 + 16 Bilateral	0.0160121
9	H&C of 8 + 16 Bilateral	0.0127239
10	Circle of 10 + 30 Bilateral	0.0101571
11	H&C of 10 + 30 Bilateral	0.00843318
…		
196	Circle of 196 + 18816 Bilateral	0.0000260318
197	H&C of 196 + 18816 Bilateral	0.0000257689

Concluding Remarks

- Self-enforcing green R&D arrangements crucially depend on excludable R&D benefits and transaction costs (i.e., attrition and coordination costs).
- Allowing transfers within green R&D agreements does not always enhance efficiency and limits the size of stable agreements, since it increases the incentives to free ride.

Thank you!

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