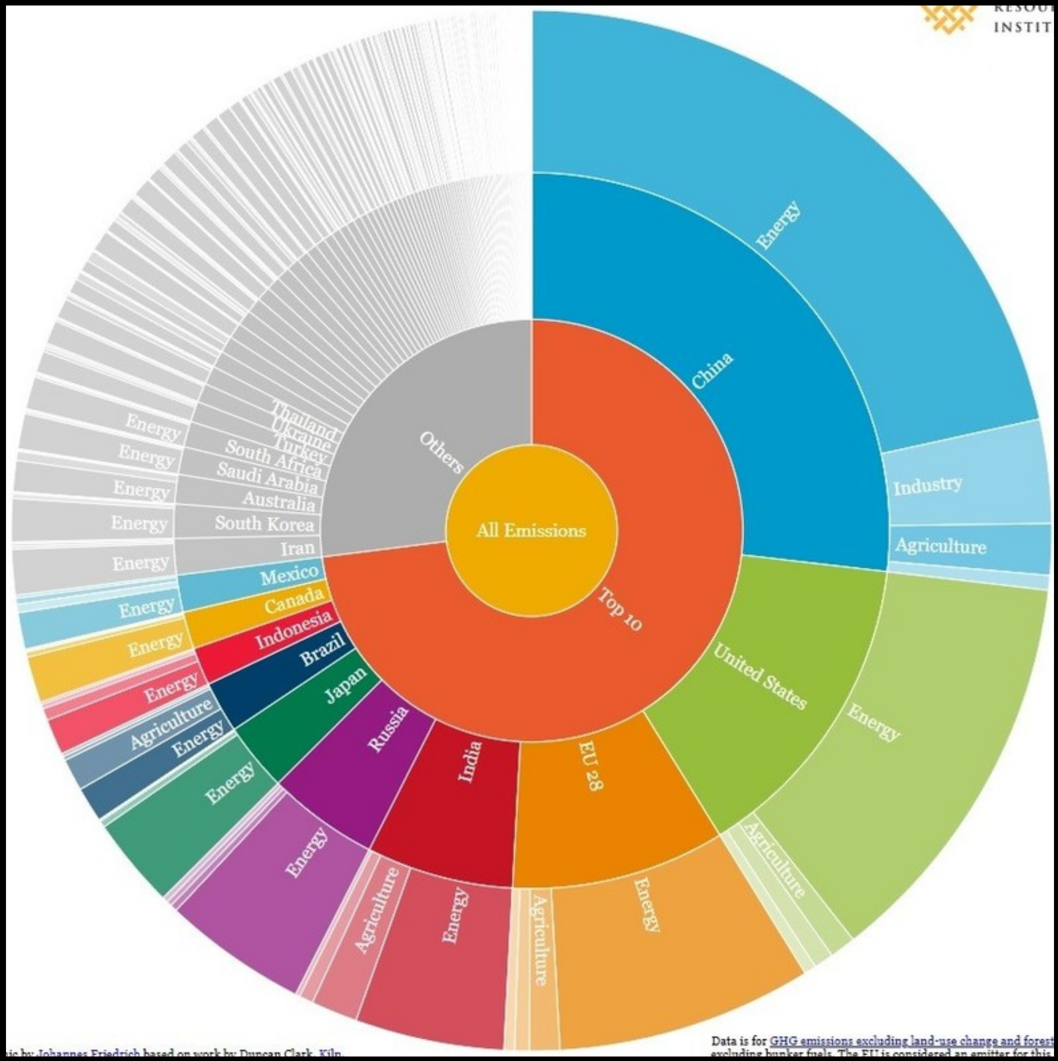
Getting to Zero: Climate Technology Treaties

Scott Barrett

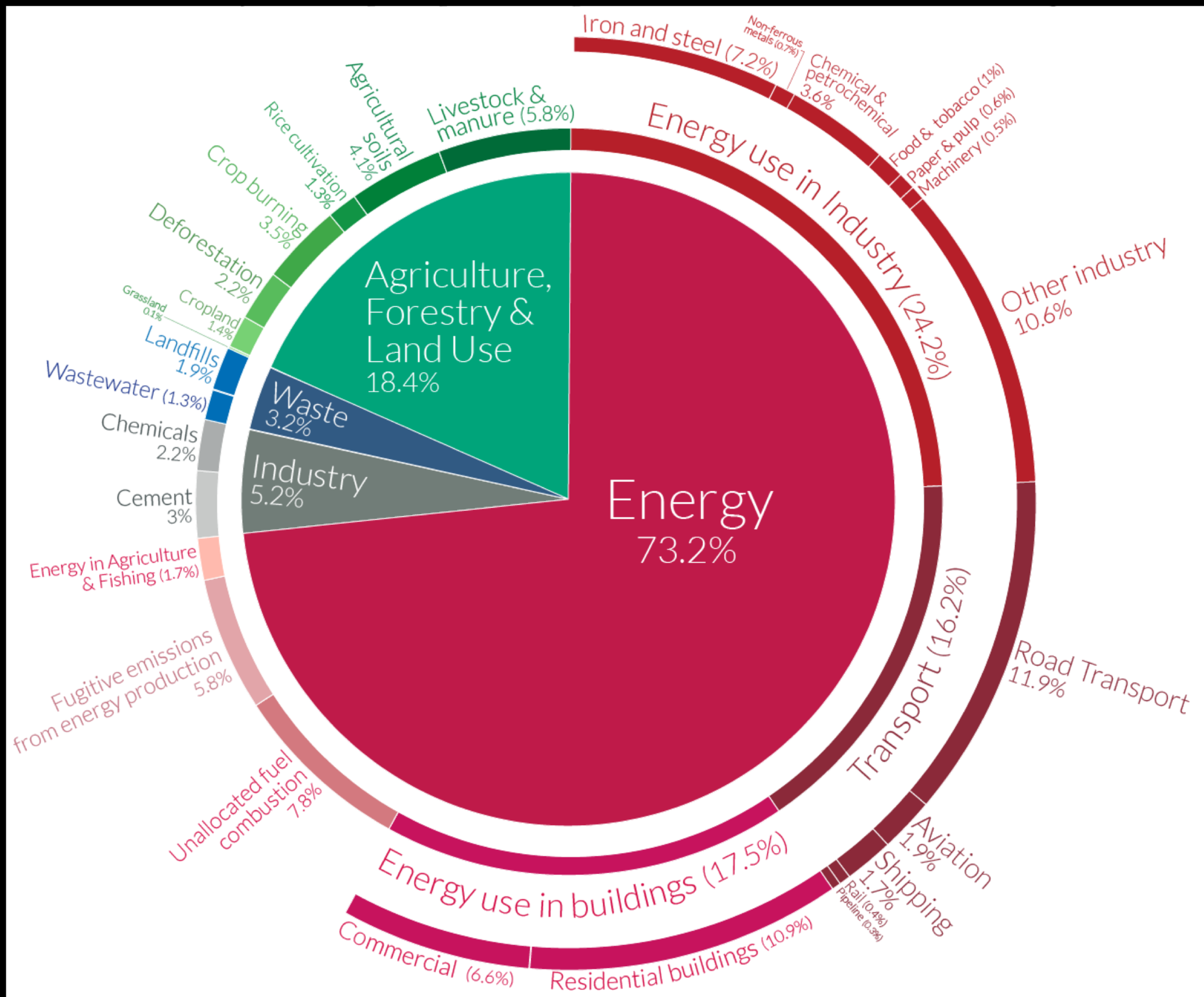
Columbia University, Sciences Po, LSE


CAUTION

Instead of this



This


Energy
73.2%
Agriculture, Forestry & Land Use
18.4%
Waste
3.2%
Industry
5.2%
Energy use in Industry (24.2%)
Transport (16.2%)
Energy use in buildings (17.5%)
Iron and steel (7.2%)
Non-ferrous metals (0.7%)
Chemical & petrochemical
3.6%
Food & tobacco (1%)
Paper & pulp (0.6%)
Machinery (0.5%)
Other industry
10.6%
Road Transport
11.9%
Aviation
1.9%
Shipping
1.7%
Rail (0.4%)
Pipeline (0.3%)
Residential buildings (10.9%)
Commercial (6.6%)
Unallocated fuel combustion
7.8%
Fugitive emissions from energy production
5.8%
Energy in Agriculture & Fishing (1.7%)
Cement
3%
Chemicals
2.2%
Wastewater (1.3%)
Landfills
1.9%
Grassland
0.1%
Cropland
1.4%
Deforestation
2.2%
Crop burning
3.5%
Rice cultivation
1.3%
Agricultural soils
4.1%
Livestock & manure (5.8%)

Purpose

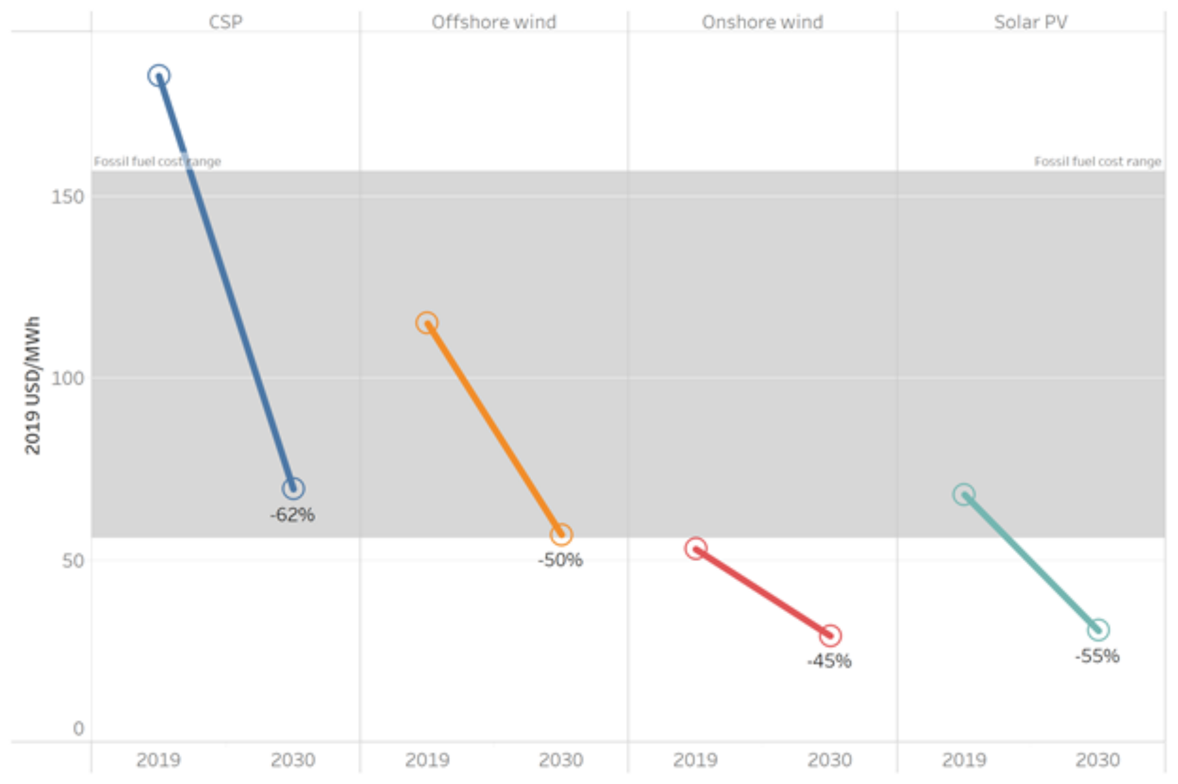
- The usual focus is on reducing the emissions of *countries*. True for treaty negotiations. True for most of the literature on IEAs.
- In this paper I explore a different approach: reducing the emissions of *sectors*, *globally*.
- The usual focus is on targets and timetables, emissions trading, and carbon taxation.
- Here my focus is on technology standards, fuel standards, strategic R&D.

Successes so far?

- BC carbon tax estimated to reduce emissions 4% in manufacturing (Ahmadi et al. 2022).
- EU ETS reduced emissions 3.8% between 2008 and 2016 (Bayer and Aklin 2020).
- Taking into account trade leakage, Aichele and Felberrmayr (2012) find that Kyoto reduced domestic emissions in Annex I countries by 7%, but “has had at best no effect on world-wide emissions.”
- Are these the right policies for getting to zero?

Successes so far?

- Montreal Protocol reduced GHG emissions 4x as much as Kyoto aspired to do (Velders et al. 2007).
- Kigali Amendment (?)
- Prices of solar PV, wind turbines, and battery storage have fallen and are expected to continue to fall....



Motivation

- The usual approach has the potential of being efficient.
- However, it may not be efficient under increasing returns.
- Also, the usual approach cannot (usually) be enforced.
- Under the right circumstances, a focus on sectors can be more efficient and more amenable to enforcement.

Emission reduction game

Emissions of country i, using technology A, are

$$E_i = E_0 e^{-t_i/\beta}, \tag{1}$$

where t_i can be interpreted either as i's carbon tax or its emissions trading equilibrium price, and E_0 represents emissions in the absence of abatement. Use of A implies positive emissions even for a very high tax. Normalize by letting $E_0 = 1$. Rewriting gives

$$t_i = -\beta \ln(E_i). \tag{2}$$

Facing this tax, A-users will reduce their emissions to the level at which $t_i = MC_i$. As $dMC_i/dE_i = -\beta/E_i$, marginal cost is decreasing in emissions (increasing in abatement). The total costs of limiting emissions to $\hat{E}_i$ are

$$TC_i(\hat{E}_i) = -\beta \int_{\hat{E}_i}^{1} \ln E_i dE_i\,. \tag{3}$$

Integrating by parts and evaluating the integral gives

$$TC_i(\hat{E}_i) = \beta[1 - \hat{E}_i(1 - \ln\hat{E}_i)]. \tag{4}$$

Obviously, $TC_i(1) = 0$. Using L'Hôpital's rule, $\lim_{\hat{E}_i \to 0} \hat{E}_i \ln\hat{E}_i = 0$, and so $\lim_{\hat{E}_i \to 0} TC(\hat{E}_i) = \beta$

Emission reduction game

Denote country i's social cost of carbon by γ. The global social cost of carbon is thus γn. Country i's payoff is

$$\pi_i^A(E_i; E_{-i}) = \gamma[(1 - E_i) + (n - 1 - E_{-i})] - \beta[1 - E_i(1 - \ln E_i)], \tag{5}$$

where $E_{-i} = \sum_{j \neq i}^{n} E_j$. It is easy to confirm that $\pi_i^A(1; n-1) = 0$ and $\lim_{E_i \to 0} \pi_i^A(E_i; 0) = \gamma n - \beta$. Maximizing gives the symmetric Nash equilibrium

$$E_{NE}^A = e^{-\gamma/\beta}. \tag{6}$$

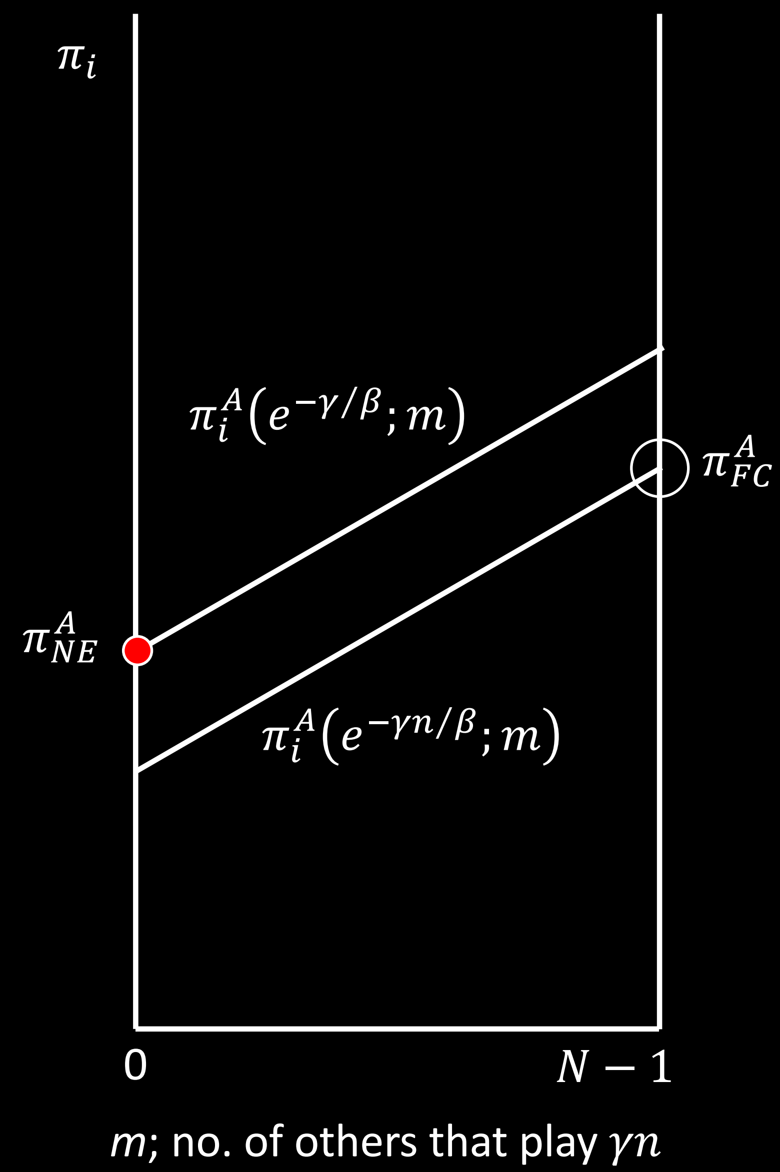
Upon substituting,

$$\pi_{NE}^A = \gamma n\left(1 - e^{-\gamma/\beta}\right) - \beta\left[1 - e^{-\gamma/\beta}(1 + \gamma/\beta)\right]. \tag{7}$$

Emission reduction game

In the full cooperative outcome, we need only substitute γn for γ. One approach to reducing greenhouse gas emissions is to urge countries to impose a carbon tax equal to γn—or, equivalently, to limit their emissions to $E_{FC}^{A} = e^{-\gamma n/\beta}$. This approach, however, runs headlong into the prisoners' dilemma, as shown in Figure 1a. Here, m represents, from any country i's perspective, the number of other countries that emit E_{FC}^{A} rather than E_{NE}^{A}.

1a. Emission Reductions Game



Technology switch game

Technology A has had the benefit of a long history of innovation and learning by doing. Technology B lacks these advantages, but exhibits increasing returns and can achieve zero-emissions. Let k denote the number of other countries, from any country's perspective, that switch from A to B ($n - k$ is thus the number of other countries that don't switch). In the Switch-to-B game, assume to begin that country i gets

$$\pi_i^B = \gamma(n-k-1)\left(1-e^{-\gamma/\beta}\right) + \gamma(k+1) - C\left(n-\alpha^B k\right) \qquad (9a)$$

if it switches, and

$$\pi_i^A = \gamma(n-k)\left(1-e^{-\gamma/\beta}\right) + \gamma k - \beta\left[1-e^{-\gamma/\beta}\left(1-\ln e^{-\gamma/\beta}\right)\right] n/\left(n-\alpha^A k\right) \qquad (9b)$$

if it doesn't switch. In (9a), Cn represents the cost to i of replacing A with B if no other countries switch (Norway's cost of promoting electric vehicles is about €1,370/tCO_2; Fridstrøm (2021). In the equation, this cost falls by $C\alpha^B$ with every additional switch.. Parameter α^B captures the returns globally to adoption of technology B; $\alpha^B > 0$ implies increasing returns, $\alpha^B = 0$ constant returns, and $\alpha^B < 0$ decreasing returns. The parameter α^A plays a similar role as regards technology A. See Arthur (1989).

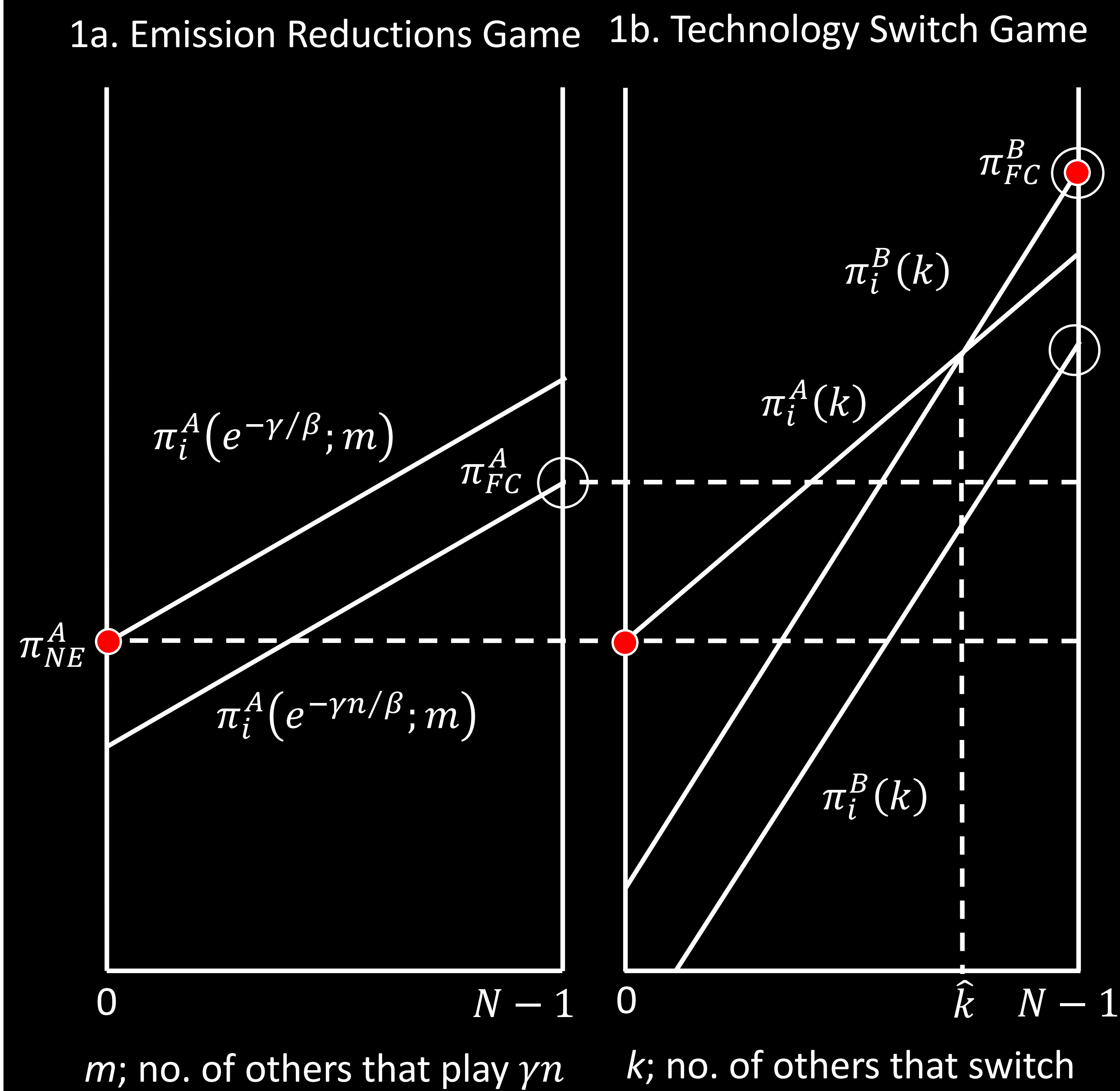


Figure 1b shows the game of getting countries to switch. Here, $\alpha^A \approx 0$.. If the lower payoff curve for B applies, the game is a prisoners' dilemma. If the upper one applies, the game is a coordination game. In this case, it not only pays all countries to switch, but switching sustains the full cooperative outcome as a Nash equilibrium. Notice, however, that switching is risky. If few others switch, switching is very costly.

Technology switch treaty

How to get countries to switch when switching to B is both a NE and efficient?

Stage 1. Every country decides independently whether to participate.

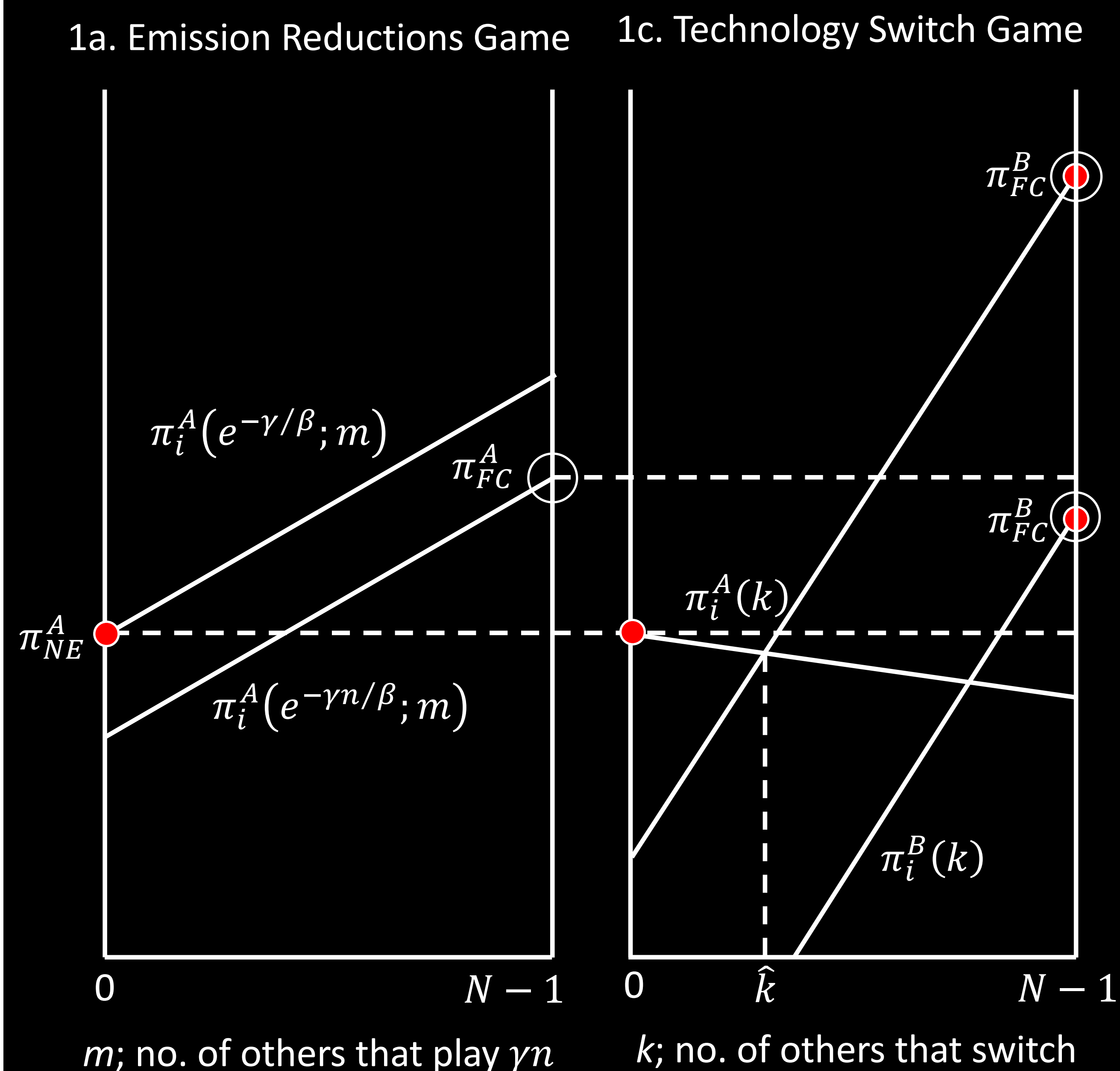
Stage 2. Parties decide collectively whether to switch.

Stage 3. Non-parties decide individually whether to switch.

Stage 3: Non-parties will switch for sure provided $k \geq \hat{k}$.

Stage 2: Parties decide collectively to switch iff $k \geq \hat{k}$.

Stage 1: All countries participate and all switch.

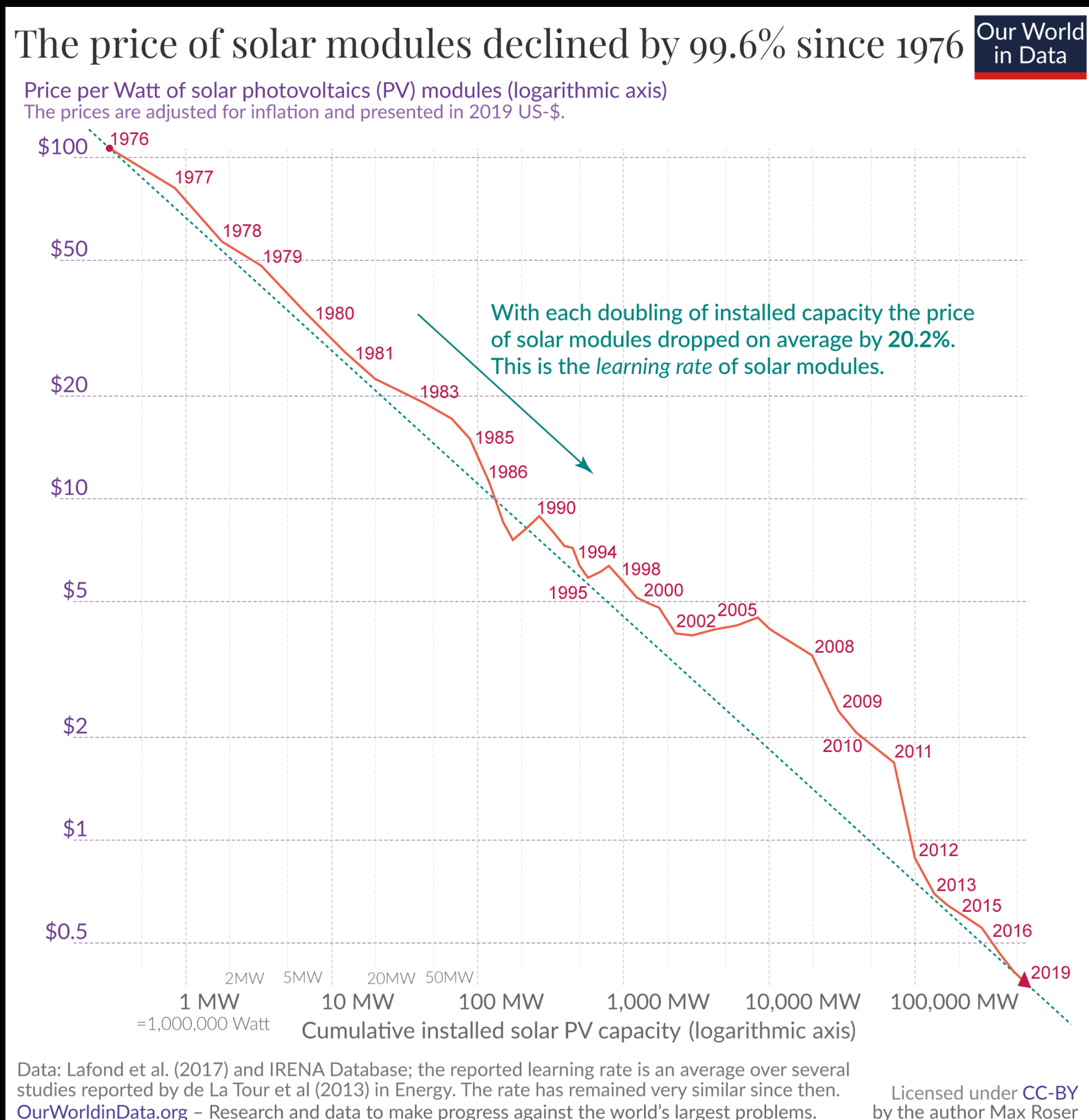


Here, α^A is "large." If the top payoff curve for switching applies, the tipping point is relatively low; switching is both payoff and risk dominant. If the bottom payoff applies, switching sustains a Nash equilibrium that is welfare superior to the Nash equilibrium in the incremental game, but inferior to the full cooperative outcome in the Emissions Reductions Game. Switching is better, but only if countries see the strategic advantage in switching.

Some examples

- **International aviation** (ICAO). Switch to synthetic fuel made from “green” hydrogen and CO_2 from air.
- **International shipping** (IMO). Switch to ammonia made with hydrogen and nitrogen from air. Engines, ships, and ports must be altered.
- Aluminium. Switch from carbon to inert anode.
- Iron and steel. Switch from blast furnace/basic oxygen furnace to direct reduction iron (made with hydrogen)/electric arc furnace.

R&D



- Solar PV costs have fallen dramatically, and Kavlak et al. (2018) estimate that public and private R&D account for 59% of this, economies of scale 22%, and learning by doing 7%.
- R&D particularly important early on.
- Combined efforts of several countries (Nemet 2019).
- To the IEA, solar PV "is becoming the lowest-cost option for electricity generation in most of the world and is expected to propel investment in the coming years."

Strategic R&D game

It may pay to invest in R&D not (only) to lower cost but to transform what would have been a PD into a coordination game.

Two stage game. In first, countries choose whether to supply R&D. In the second they decide whether to adopt A or B. Start by analyzing the stage 2 game.

Let costs be $C = Ce^{-\eta R}$, where $R = \sum_{i=1}^{n} r_i$. The payoff to switching then becomes

$$\pi_i^B(R; k) = \gamma(n - k - 1)\left(1 - e^{-\gamma/\beta}\right) + \gamma(k + 1) - Ce^{-\eta R}\left(n - \alpha^B k\right).$$

Of particular importance is the effect of R&D on the incentive to switch when $k = n - 1$. Switching is payoff-dominant if

$$\pi^B(n-1; R) > \pi^A(n-1) \Leftrightarrow \gamma e^{-\gamma/\beta} + \frac{\beta n\left[1 - e^{-\gamma/\beta}(1 + \gamma/\beta)\right]}{[n - \alpha^A(n-1)]}$$
$$> Ce^{-\eta R}[n - \alpha^B(n-1)].$$

A higher R plainly makes this inequality more likely.

Stage 1 game

Consider case in which previous expenditure on R&D transforms the prisoners' dilemma into a coordination game. Assume $R \in \{0, \hat{R}\}$ and that coordination on the efficient equilibrium is guaranteed. Then, aggregate willingness to pay for the R&D is

$$n\left[\pi_{FC}^{B}(\hat{R}) - \pi_{NE}^{A}\right]$$
$$= n\left\{\gamma n e^{-\gamma/\beta} + \beta\left[1 - e^{-\gamma/\beta}(1 + \gamma/\beta)\right] - Ce^{-\eta\hat{R}}[n - \alpha^{B}(n-1)]\right\}.$$

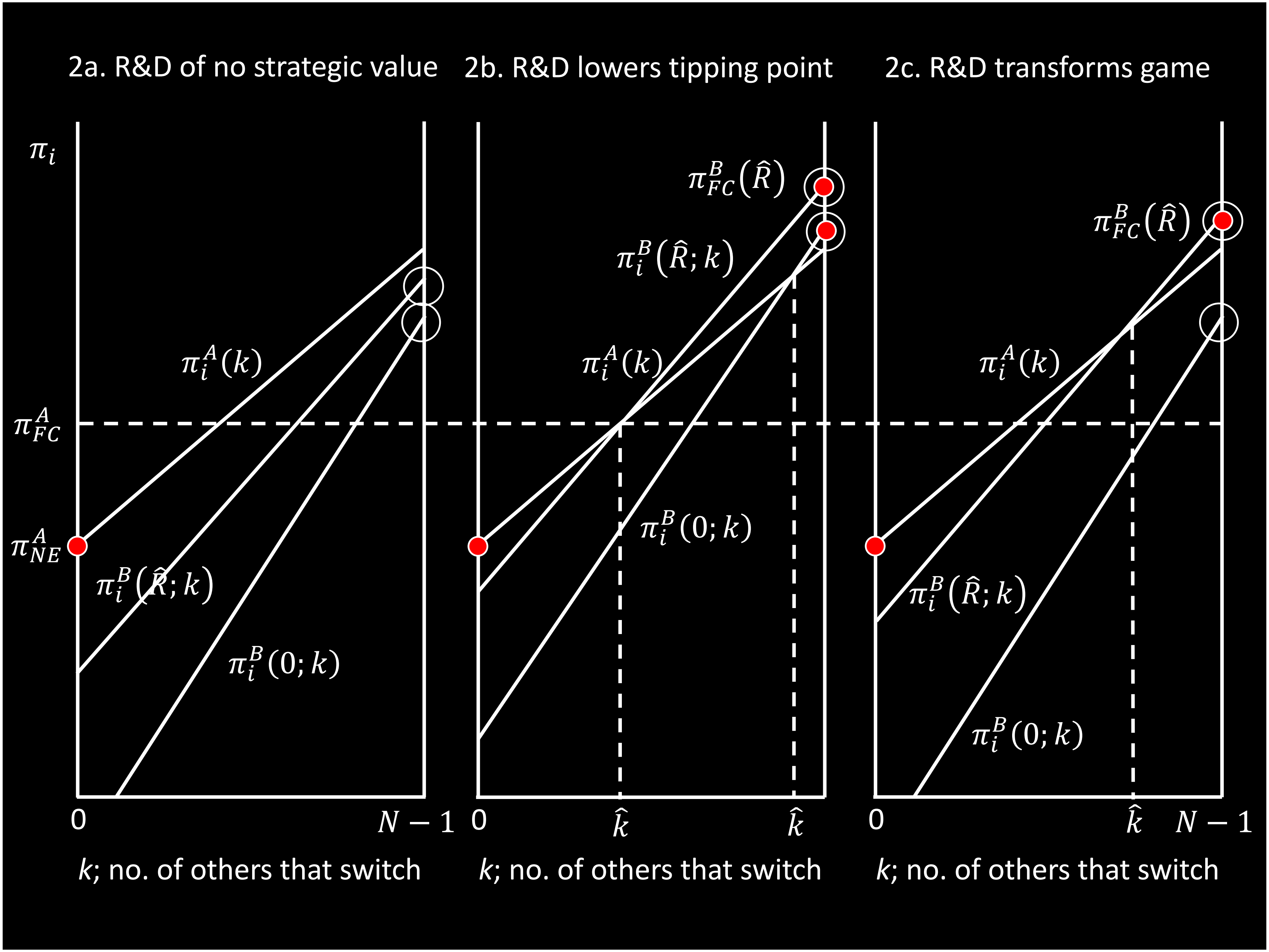
It will pay all states collectively to supply the budget fully iff

$$\hat{R} \leq n\left\{\gamma n e^{-\gamma/\beta} + \beta\left[1 - e^{-\gamma/\beta}(1 + \gamma/\beta)\right] - Ce^{-\eta\hat{R}}[n - \alpha^{B}(n-1)]\right\};$$

Of particular interest is the situation in which it doesn't pay any country to supply $\hat{R}$ unilaterally but it pays all countries to supply $\hat{R}$ collectively. This implies

$$\hat{R} > \gamma n e^{-\gamma/\beta} + \beta\left[1 - e^{-\gamma/\beta}(1 + \gamma/\beta)\right] - Ce^{-\eta\hat{R}}[n - \alpha^{B}(n-1)] > \hat{R}/n\,.$$

In this case, international cooperation is needed to fund the R&D. Of course, it needn't be the case that all countries must cooperate to supply the R&D.


2a. R&D of no strategic value
2b. R&D lowers tipping point
2c. R&D transforms game
π_i
π_{FC}^A
π_{NE}^A
$\pi_i^A(k)$
$\pi_i^B(\hat{R};k)$
$\pi_i^B(0;k)$
$\pi_{FC}^B(\hat{R})$
0
$N-1$
$\hat{k}$
$\bar{k}$
k; no. of others that switch

Earth Shots

- Hydrogen Shot. Goal to reduce the costs of “green” hydrogen 80% in 10 years.
- Carbon Negative Shot. Goal to lower cost to $100/tCO2.
- Long Duration Storage Shot. Goal to reduce cost of grid-scale energy storage by 90% within a decade.

Conclusion

- Just a first look systematically at how a focus on technologies transformed globally can achieve more than the direct approach of focusing on emissions at the country level.
- The essential need is to transform the PD into a coordination game.