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The Role of Innovation for Long-Term GHG Mitigation

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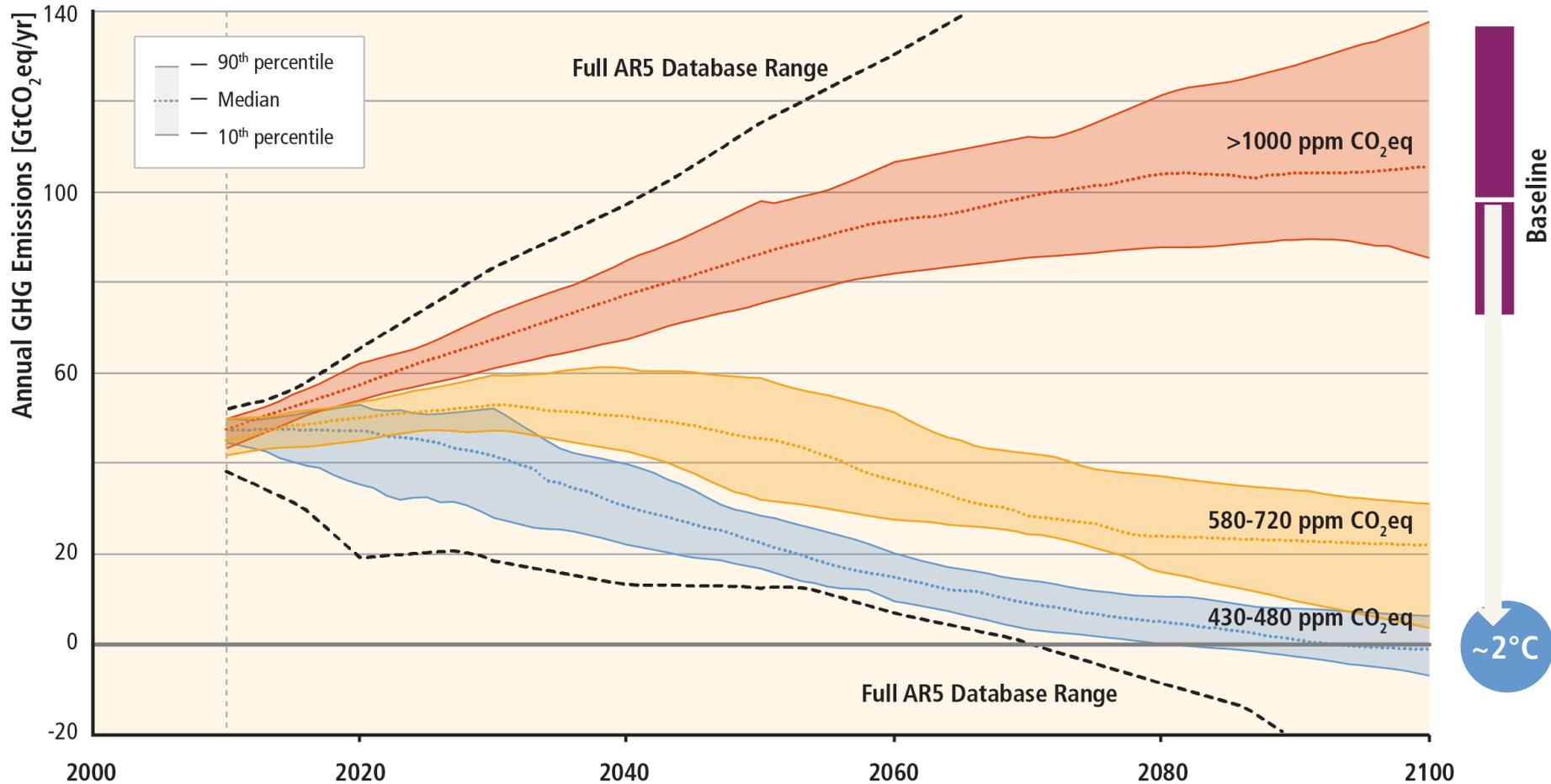
The technology challenge

If the objective is to keep temperature increase below or around 2° C, **massive investments in the development of new technologies** are necessary. In particular on:

- (i) technologies **to remove** large amounts of CO₂ from the atmosphere, and
- (ii) technologies **to store** large amounts of energy at low costs.

The first set of technologies is crucial to reduce the **stock** of past GHG emissions. The second one is crucial to increase penetration of renewables well above 40-50% of total energy demand, thus bringing the **flow** of GHG emissions close to zero.

Stabilization of atmospheric GHG concentrations requires negative emissions by the end of the century

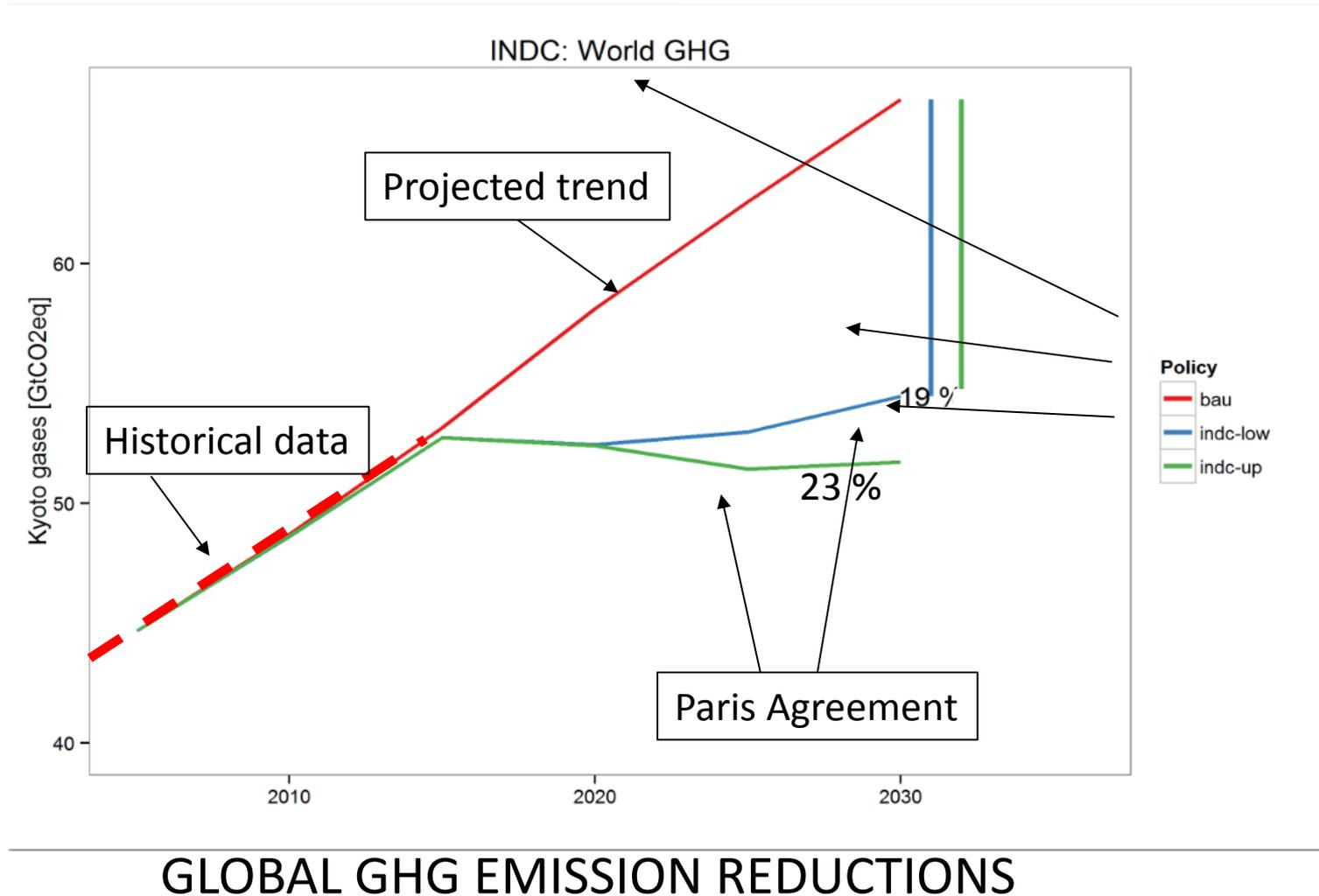


Crucial questions

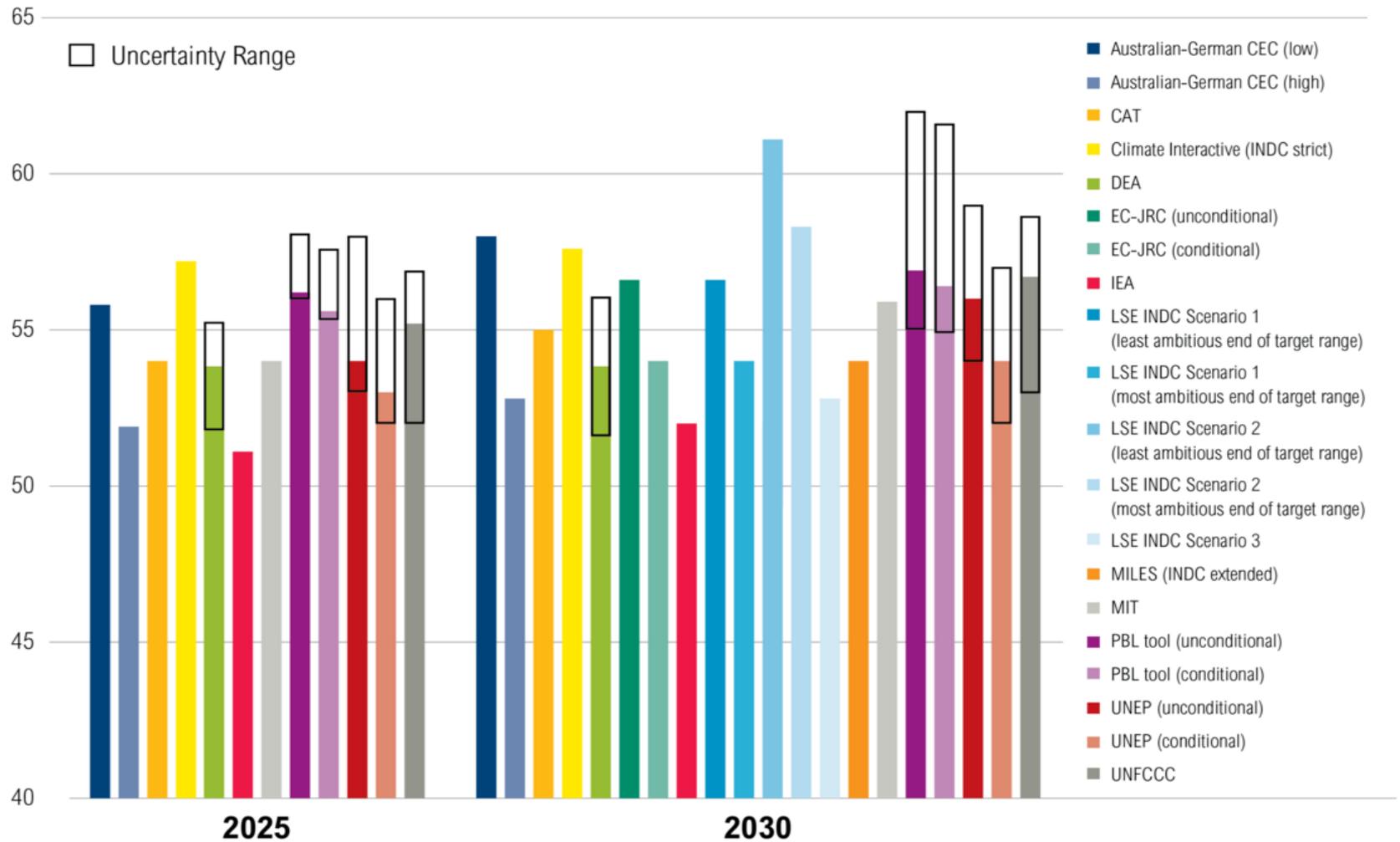
- Why do we need innovation to achieve the 2C target?
 - What kind of innovation is crucial?
 - How larger would the mitigation cost be without innovation?
 - What is the return on investments on carbon saving innovation?
 - What are the financial resources necessary for these investments?
 - What is the impact of innovation on both economic growth and emission reduction? Is there a trade-off?
 - How can climate related innovation be enhanced? (carbon pricing, subsidies, public R&D programs... etc)
 - Can innovation help the climate governance process, namely can it help the formation of a club of countries willing to achieve more ambitious emission reductions?
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The Paris Agreement

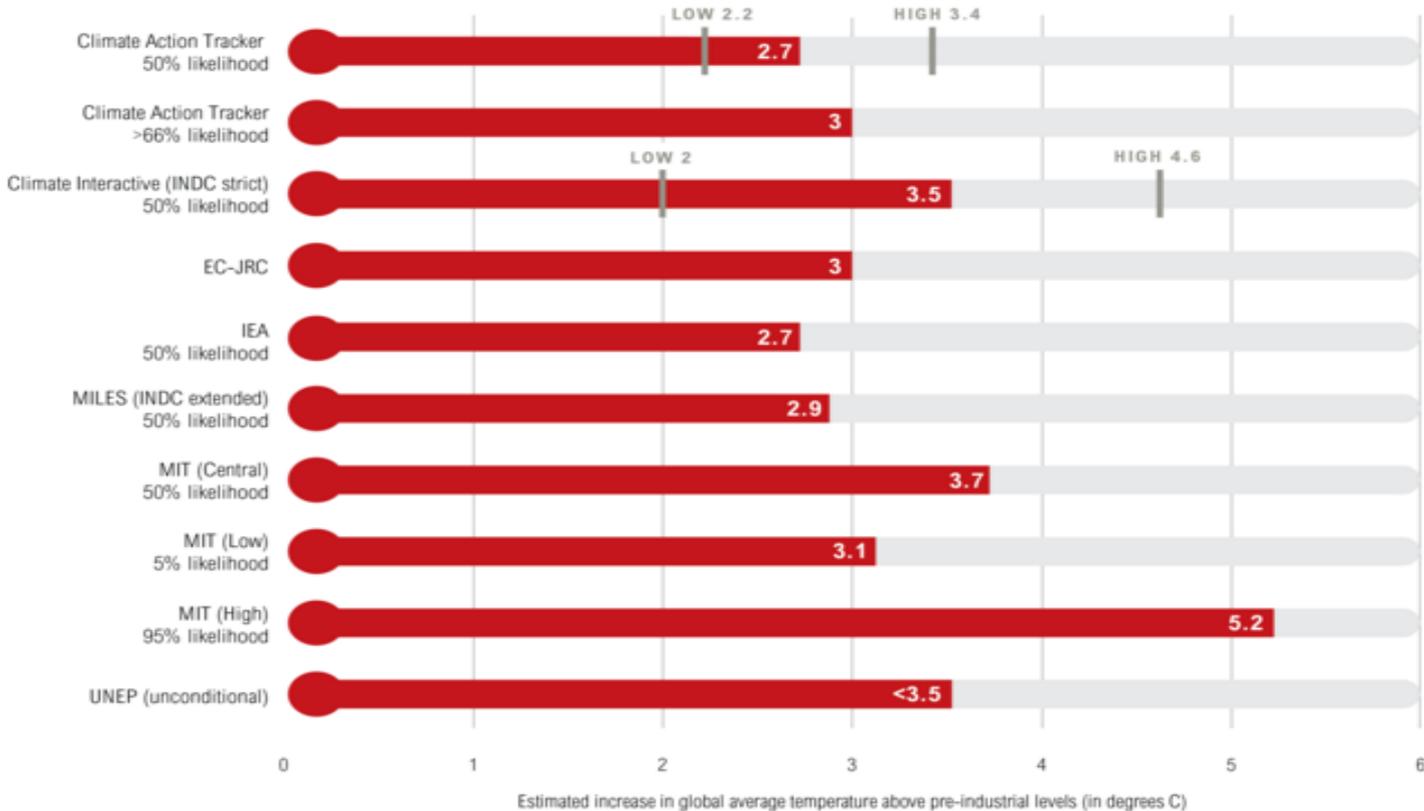
In this context, the Paris agreement is probably one of the best outcomes one can envisage:



Emissions levels in 2025 and 2030 with INDCs



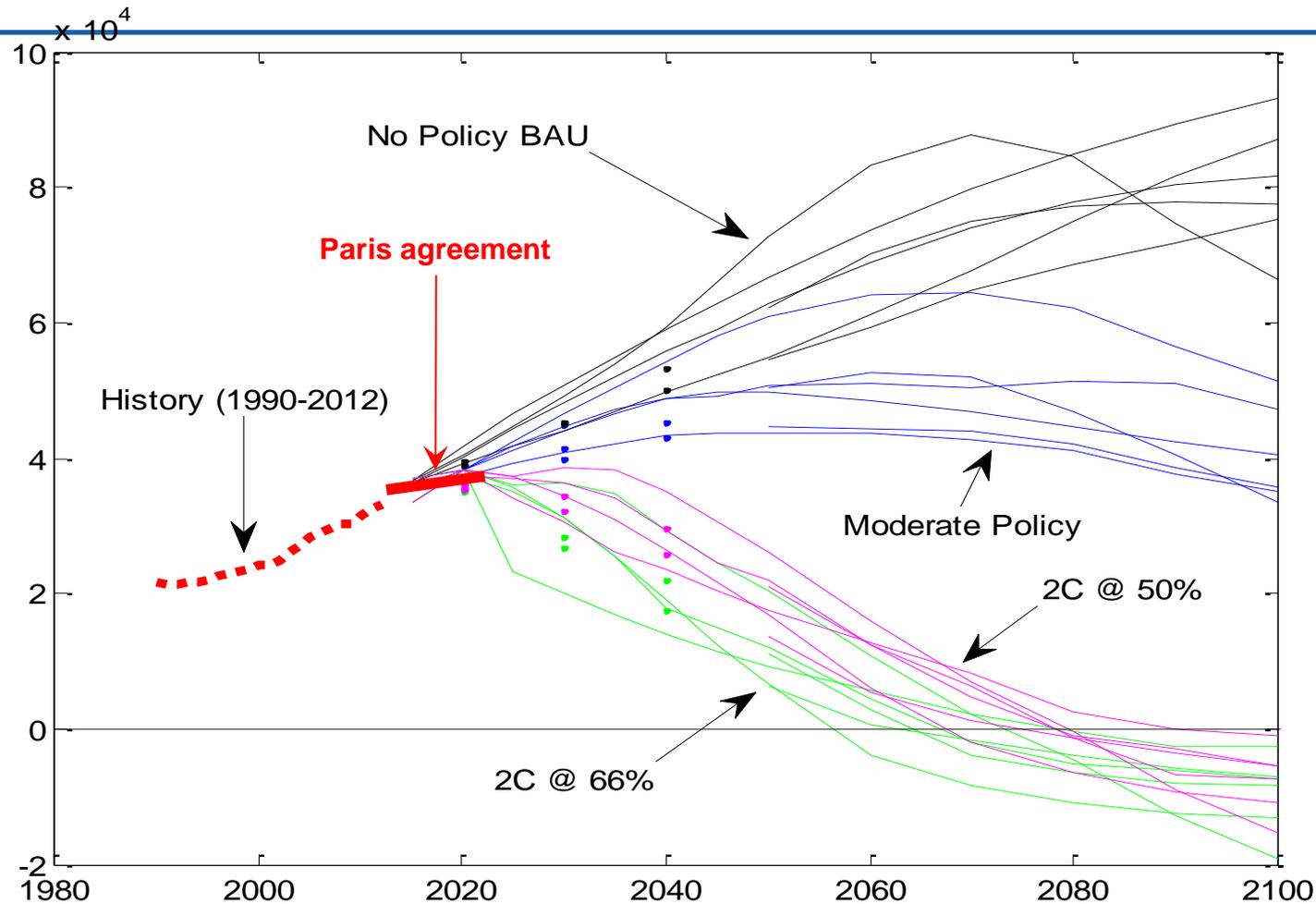
Estimates for Global Temperature Rise with INDCs



Note: "Likelihood" refers to the probability of limiting global warming to a specified temperature by 2100. For instance, >66% likelihood provides a "likely" chance that warming will not exceed the given temperature.

<http://bit.ly/indc-temp>

The Paris Agreement is insufficient if the goal is 2°C



- Achieving 2C with sufficient probability would require departing from historical trends in emissions in the next 5-10 years at most (Source: historical data: EIA/IEA; Projections: LIMITS multi model ensemble)



How can ambitious emission reductions be achieved from 2030 onward?

- Phase-out of coal
- Remove subsidies to fossil fuels
- Diffusion of energy efficiency improvements

- Efficient allocation of abatement efforts
- Carbon Pricing → Resources to support R&D and investments

- **Development and diffusion of new technologies (CO₂ removal, energy storage,.....)**

- Enhanced climate finance

Investing in R&D

Significant investments would therefore be needed, particularly in Research and Development of:

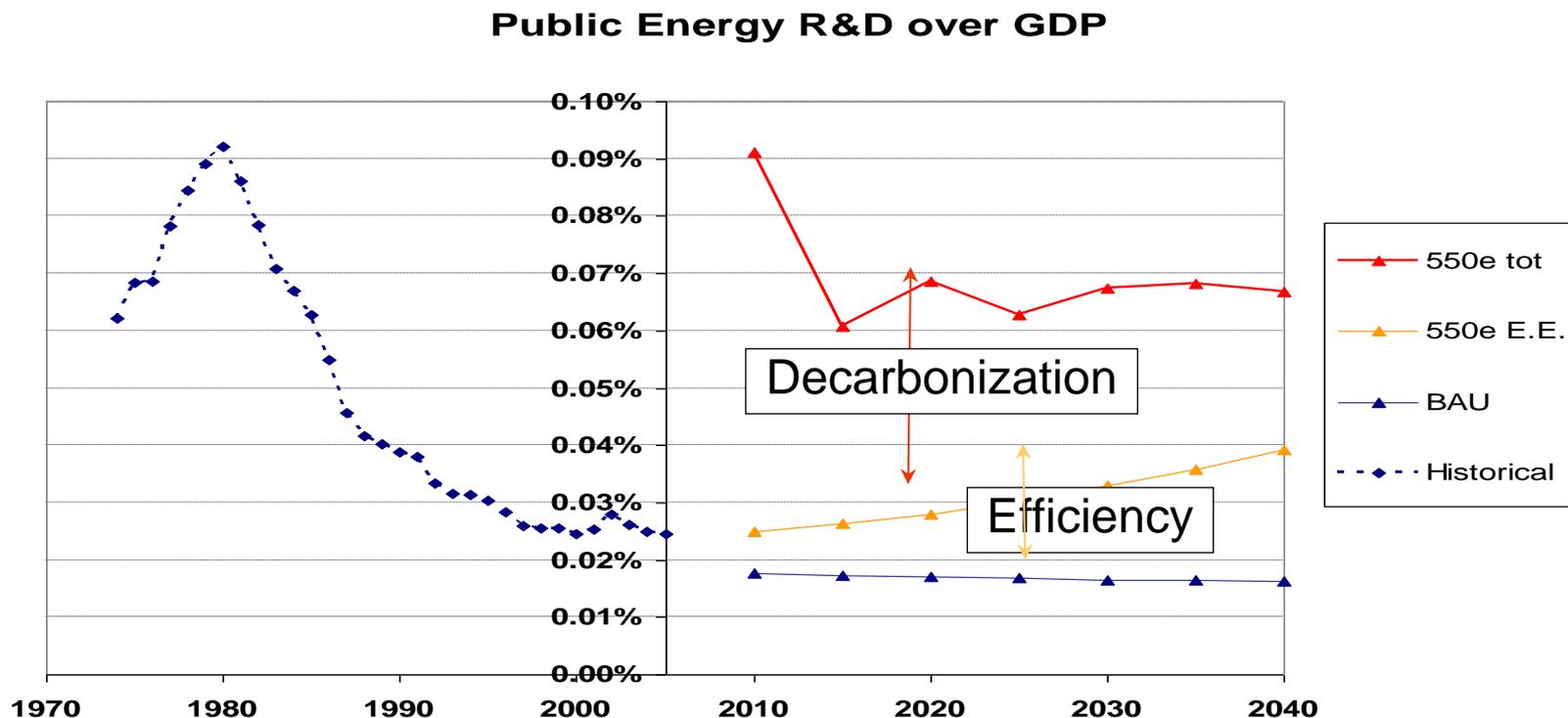
- Energy efficient technologies
- Carbon-free energy technologies
- Energy storage technologies
- Smart grids and
- CO2 removal and CO2 re-use technologies.

Yet investment in energy R&D technology have declined dramatically since the peak of the early 80s.

The Apollo Program

- Launched in June 2015, the project - named for the [Apollo Program](#), which brought together thousands of scientists and engineers to put mankind on the moon - calls for developed nations to commit to spending 0.02% of their GDP, for 10 years, to fund co-ordinated research to solve the challenge.
 - This equates to \$150 billion over a decade, roughly the same cost committed to the Apollo Program in 2015 money. Some developed nations, including the UK, already meet the GDP percentage target spend, but many do not and there is little international coordination to maximise the results.
 - It has been modelled on the more recent [International Technology Roadmap for Semiconductors](#), an international research collaborative that is credited with greatly and swiftly improving the quality and economics of semiconductor manufacture.
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Energy R&D. Past evolution and future requirements



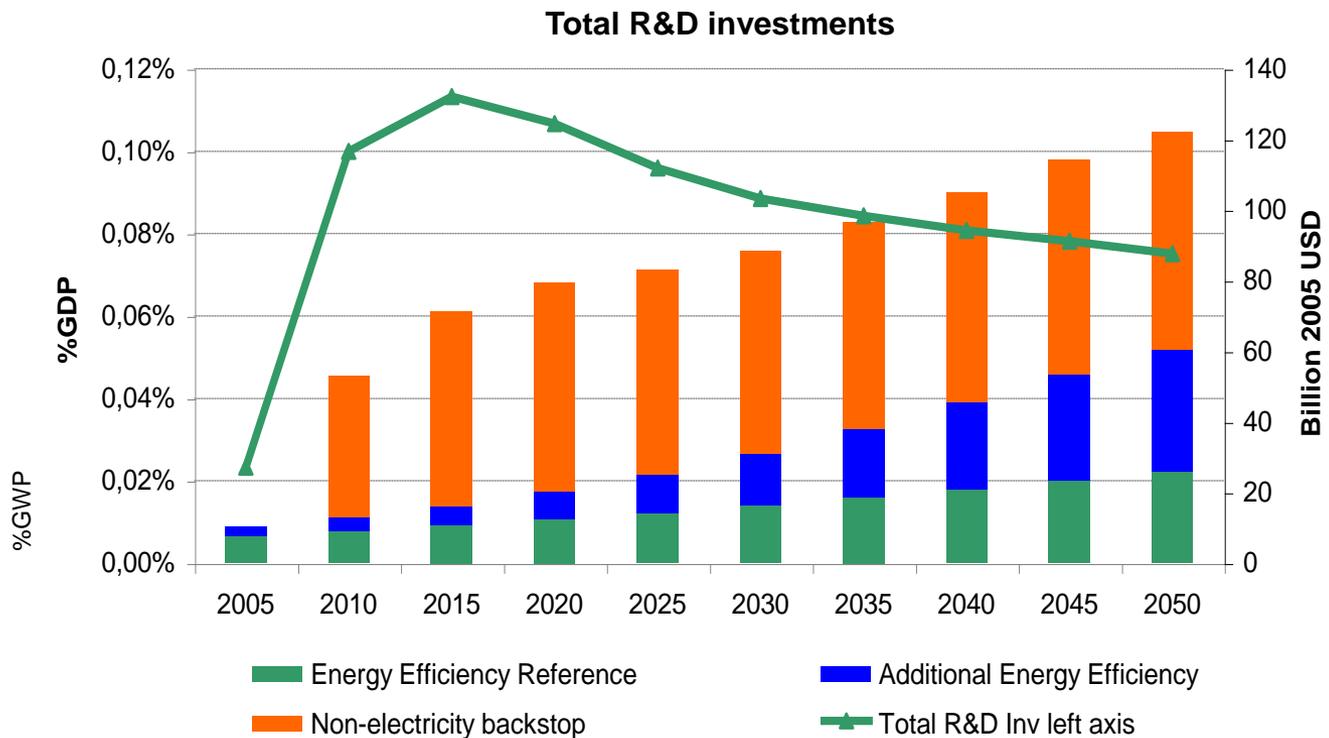
4 fold increase in public energy R&D investments needed (roughly 40 Billions/yr).

Return to 1980s figures (yet 2 order of magnitude smaller than physical investments in commercial technologies -> cheap insurance policy).

Focus on both improving efficiency but mostly on innovation in low carbon technologies, energy storage and CO2 removal.

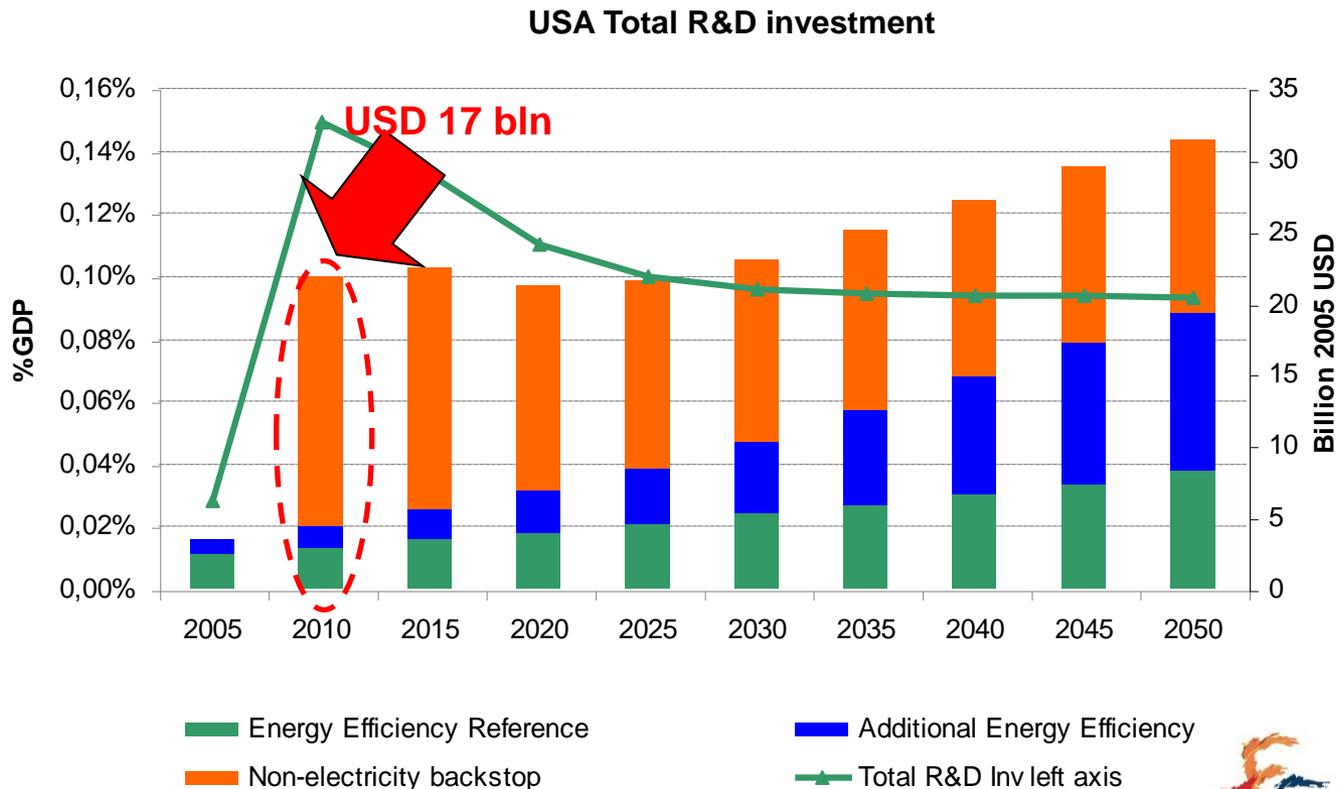
Optimal R&D Investments

- Fast expansion
- Modest in GWP terms (about 1% of GWP)
- A managerial effort rather than a purely financial effort?



Learning from the past

- The 1960s NASA Apollo Space Program 97.9 billion over 13 years (around USD 7.5 bln per year)
- Apollo Space Program investments were 0.4% of the average national GDP during the peak year



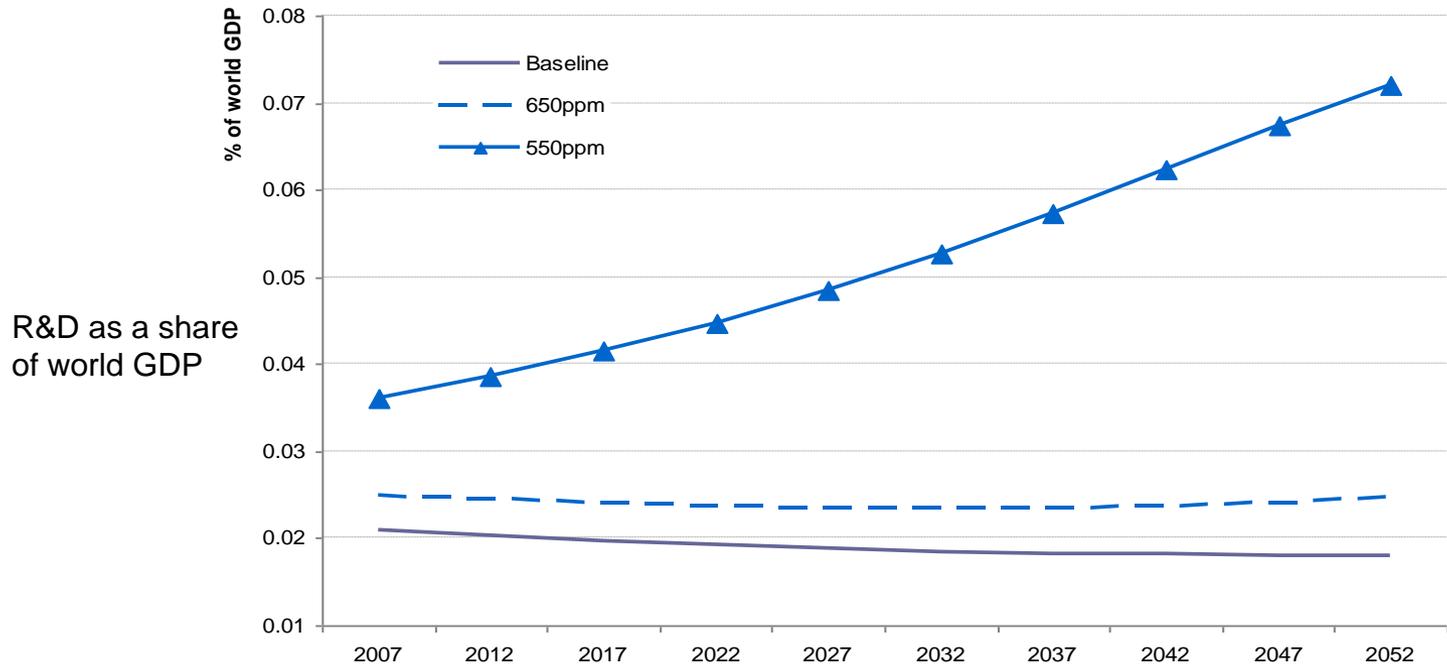
Using carbon finance

- Suppose all permits are auctioned: what share is needed to cover investments in R&D?
- Initially low carbon price and high R&D spending require about three quarters of permits to be auctioned
- In 2030 the share declines to a modest 5% mainly because the price will increase substantially after 2020

Weighing auctioned revenue and R&D investments

Years	OECD		USA		Europe	
	% of permits	R&D investments = auctioning revenue	% of permits	R&D investments = auctioning revenue	% of permits	R&D investments = auctioning revenue
2010	76%	48.128	71%	21.906	75%	15.296
2015	28%	51.151	27%	22.453	27%	15.494
2020	14%	49.917	13%	21.278	13%	15.380
2025	9%	50.634	8%	21.541	8%	15.540
2030	5%	53.686	5%	23.005	5%	16.270

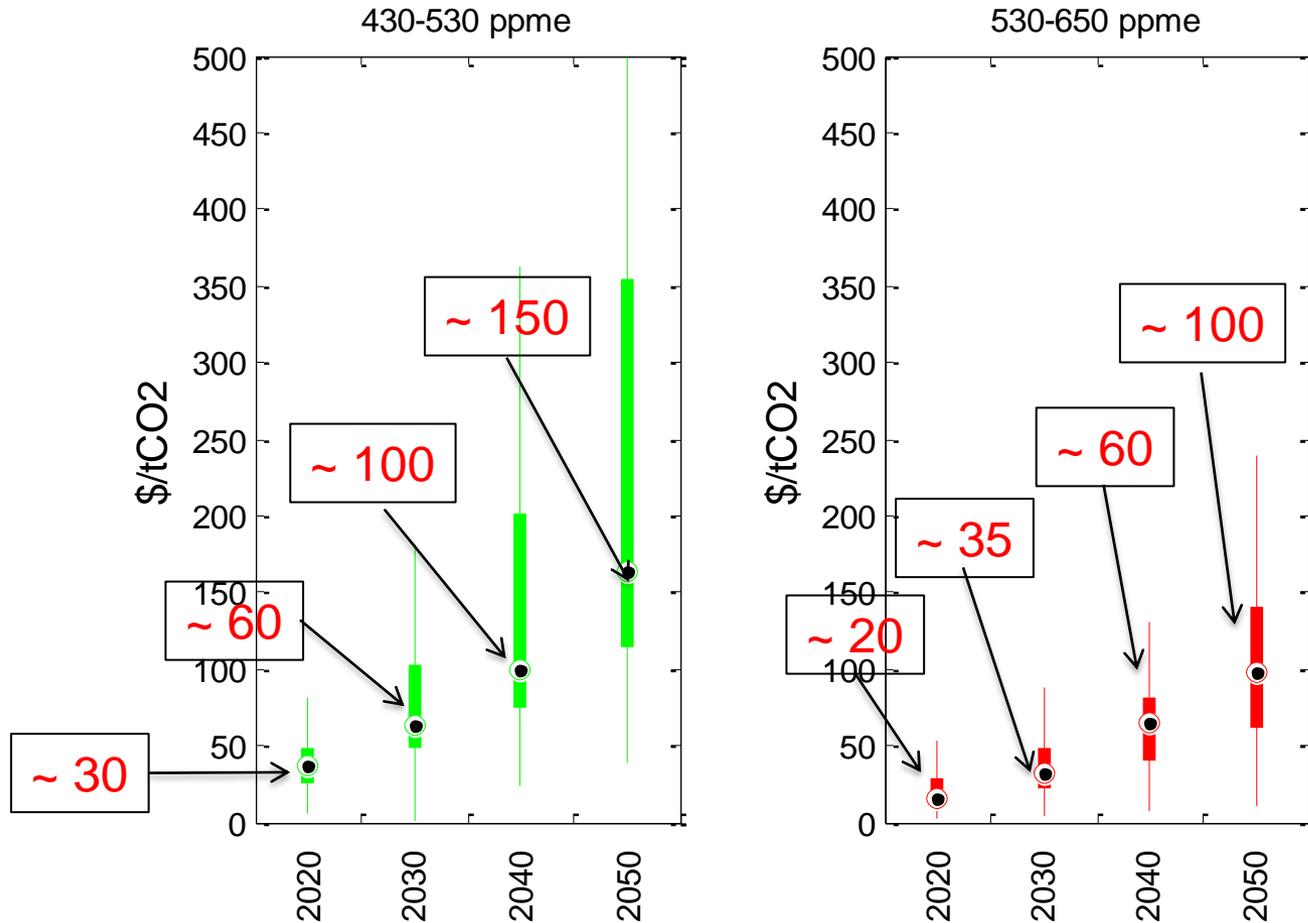
Energy efficiency R&D with and without carbon price



Investments in energy efficiency R&D are significantly higher only with a strong carbon price signal:

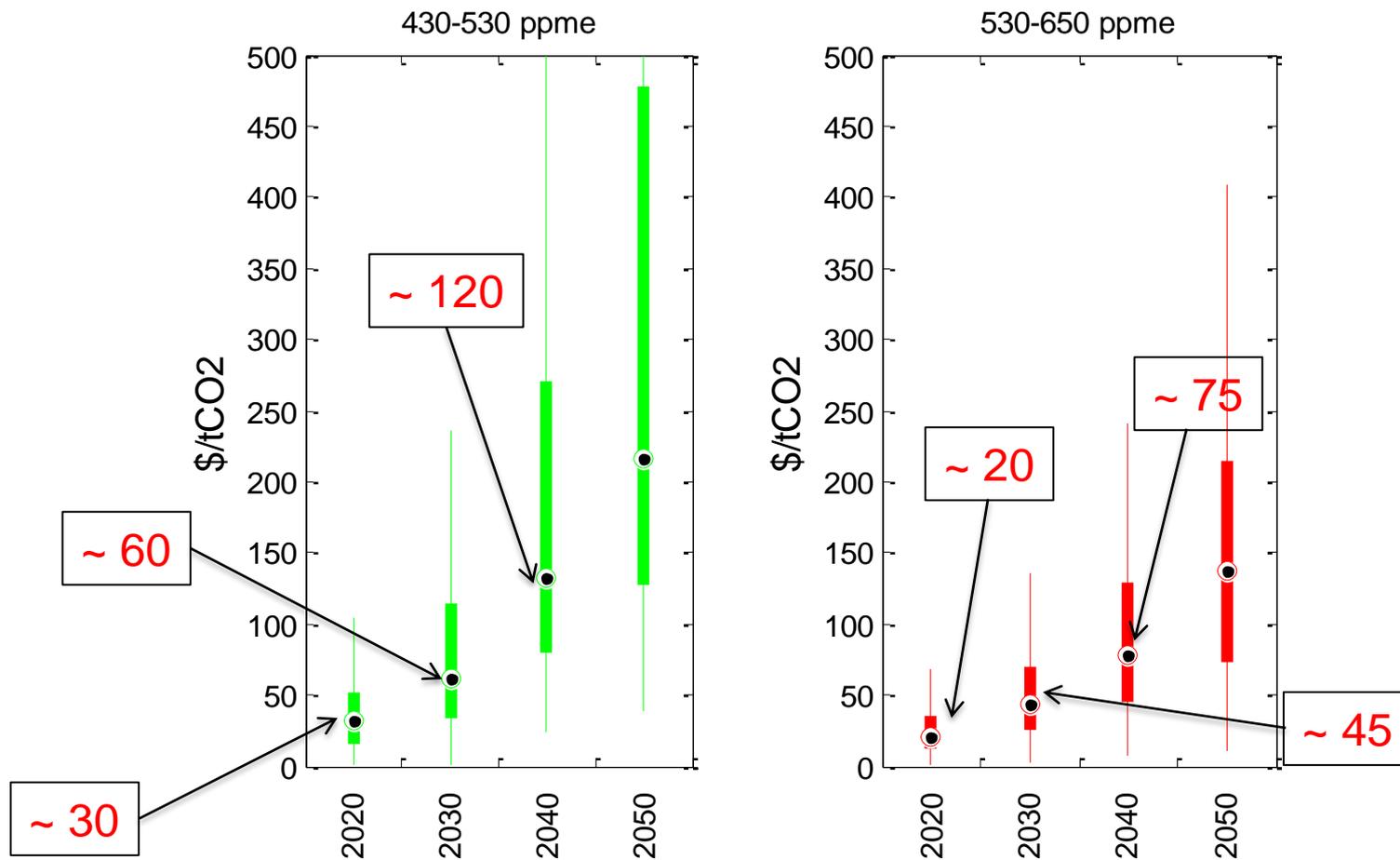
- importance of expectations about carbon prices;
- bulk of mitigation in mild scenarios undertaken in developing countries.

Global carbon prices: first best scenarios



Boxplots of model results: the central mark is the median, the edges of the box are the 25th and 75th percentiles, the whiskers extend to approx 5-95%

Global carbon prices for different climate objectives: all scenarios



Boxplots of model results: the central mark is the median, the edges of the box are the 25th and 75th percentiles, the whiskers extend to approx 5-95%

Data sources

IPCC WGIII AR5 data base, publicly available at

<https://secure.iiasa.ac.at/webapps/ene/AR5DB/dsd?Action=htmlpage&page=about>

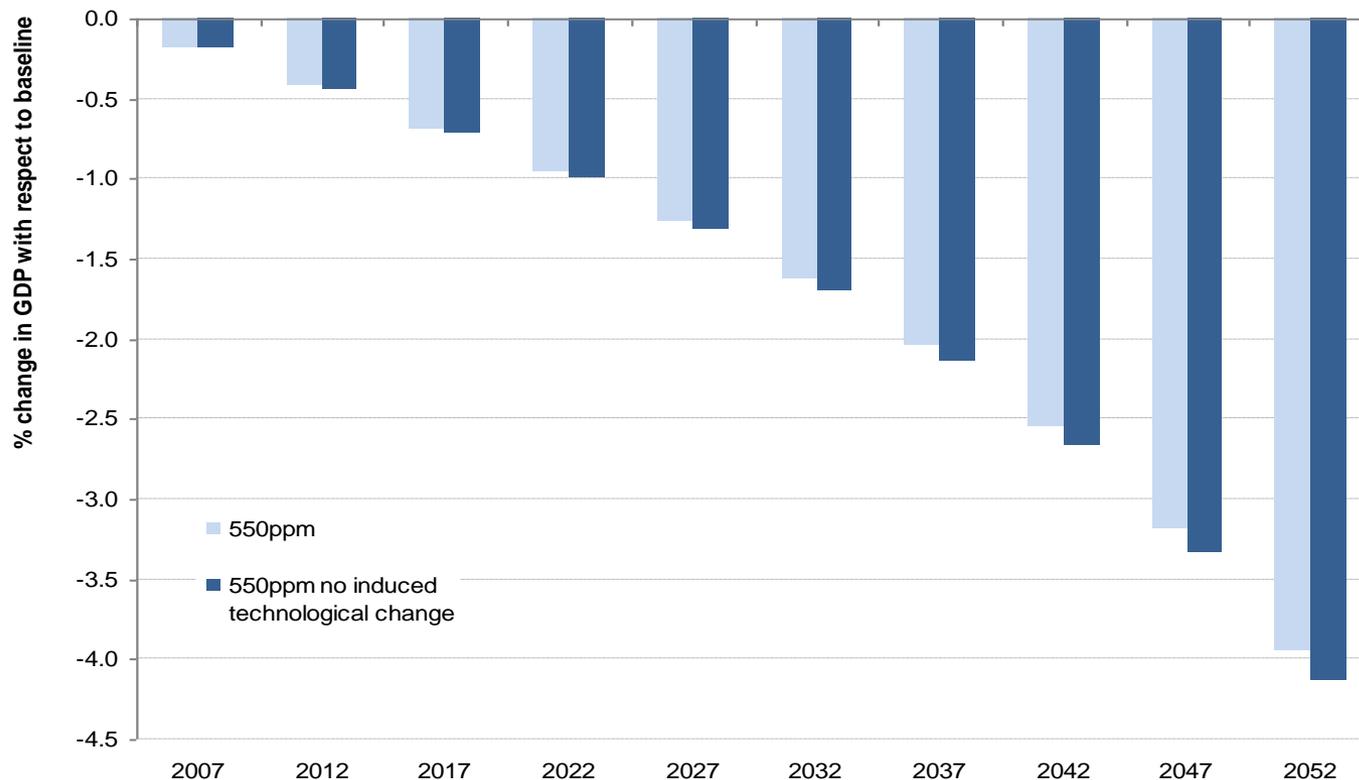
- 15 IAMs
- 1000 scenarios, spanning different climate targets and different policy architectures, and technological availability

LIMITS MIP (Tavoni et. al, Nature Climate 2015)

- 6 IAMs
- 2 non cooperative scenarios with different pledges (mimicking INDCs)
- 2 fully cooperative scenarios (450 and 500 ppm eq)
- 3 burden sharing schemes (tax, per capita convergence, equal costs)

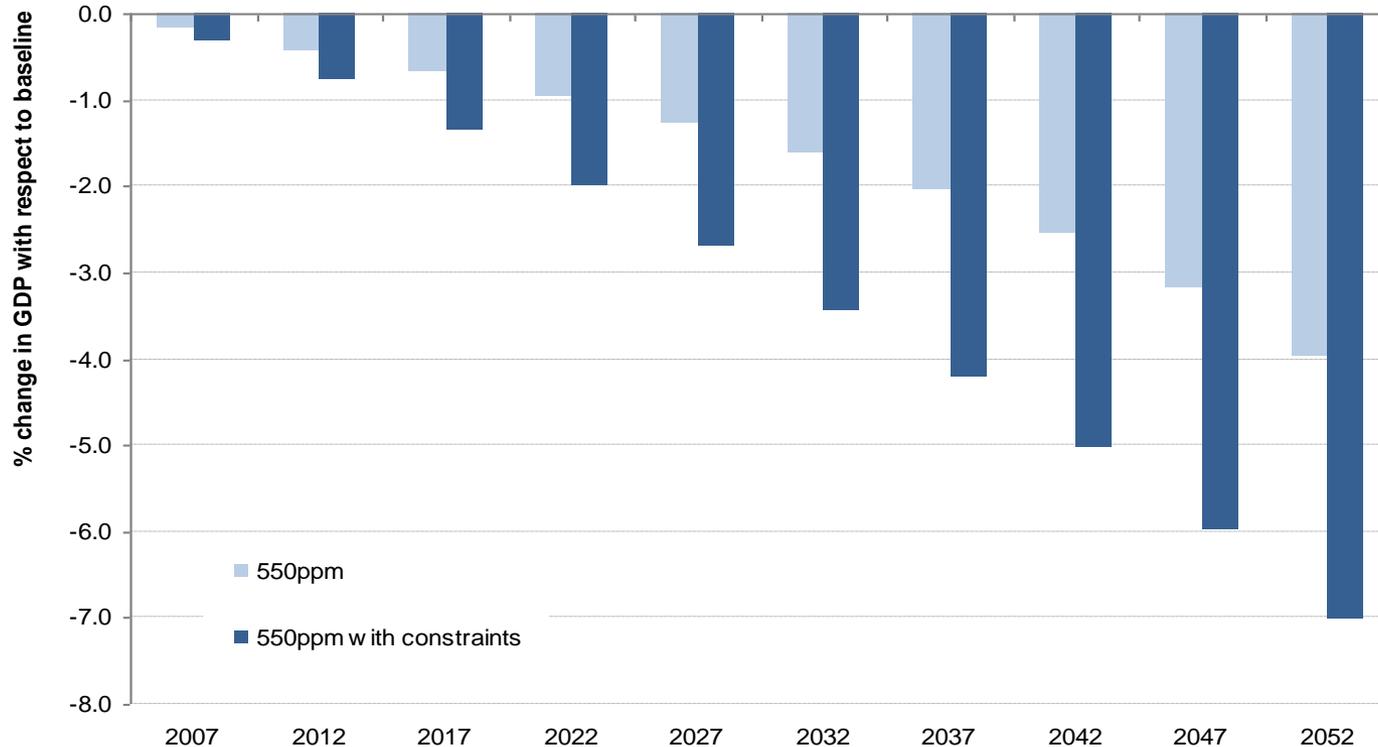
All data publicly available

The costs of mitigation with and without induced technical change



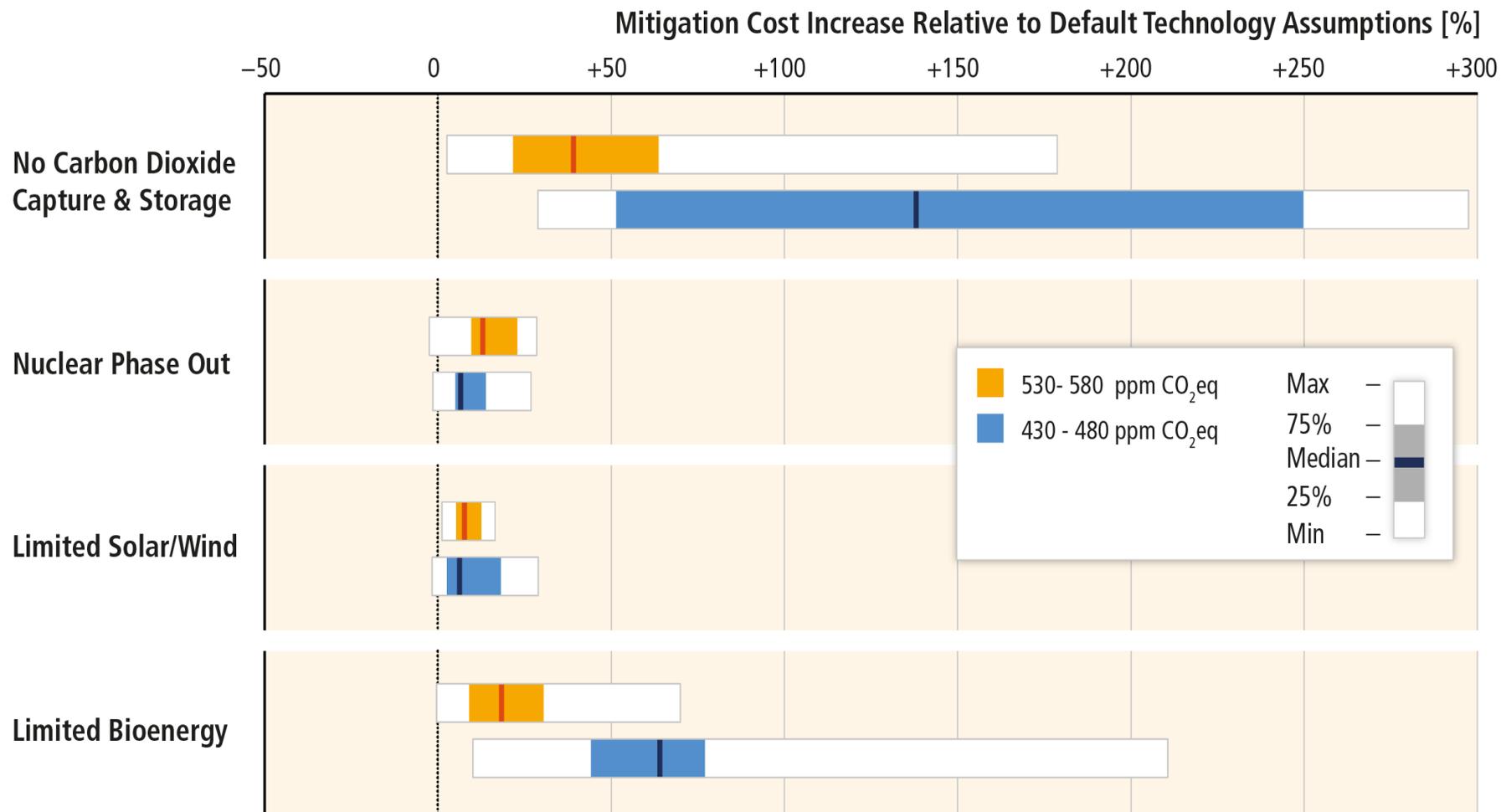
Induced technical change reduces mitigation costs, although the total impact is small. However, in this slide, technical change affects energy efficiency only. Source (OECD, 2010)

The costs of mitigation with limited technological options



Impacts on global costs are affected by the availability of technological options: costs are much higher if the deployment of carbon free technologies is constrained. Source (OECD, 2010)

Limited availability of technologies can greatly increase mitigation costs.



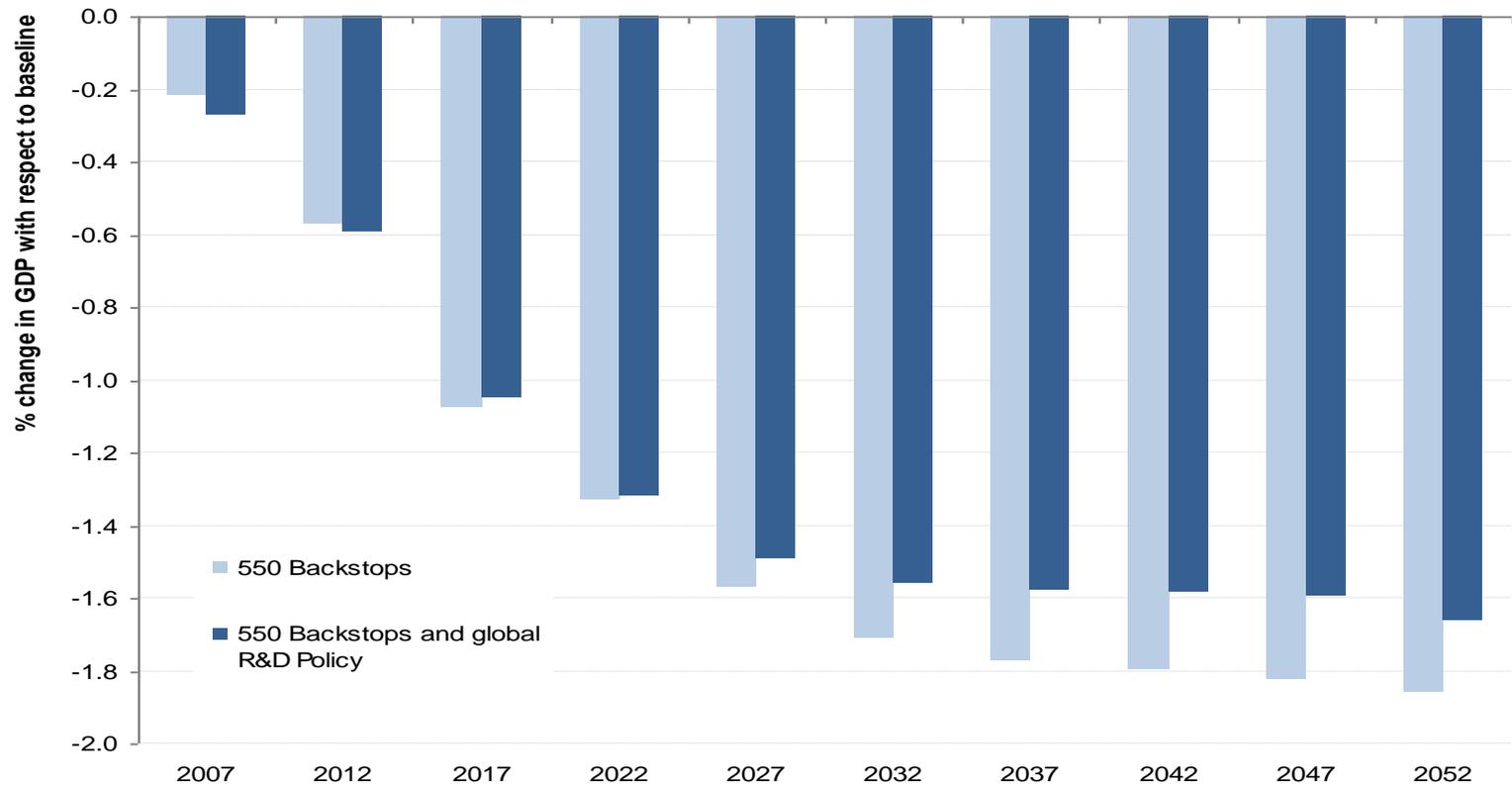
An international R&D fund

- Policy set up:
 - 550 ppm stabilization scenario
 - International Fund to finance technology development
 - Size of the Fund matching R&D investments of the 80s, starting at 0.08% of world GDP.
 - Each region contributes a share of GDP to the fund, which is reallocated on a per capita basis adding to own energy efficiency R&D efforts.

An international R&D fund: some results...

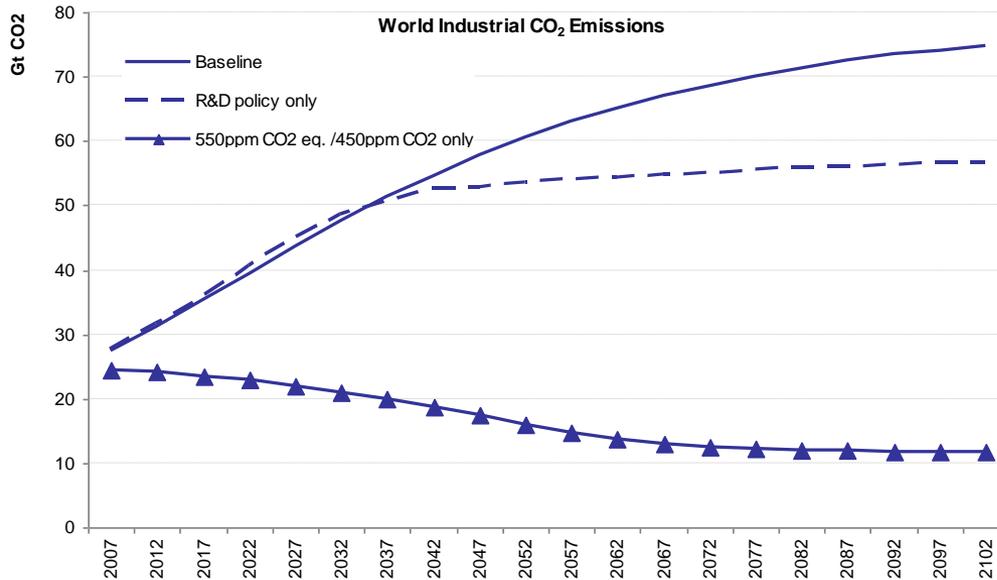
- When the Fund subsidizes investment in energy efficiency R&D, it has a limited impact on costs of meeting the mitigation target
- Indeed, when the knowledge externality is internalised, the carbon price signal alone has significant impacts on energy prices and stimulates R&D investments, so the additional R&D subsidy on energy efficiency has a low marginal effect.
- The Fund has more impact when used to help “deeply decarbonise” the economy
 - Subsidizes R&D in the backstops (eg CO₂ removal and/or large storage technology)
 - Subsidizes the deployment of existing low carbon technologies

Mitigation costs with a global fund to finance R&D in the backstops



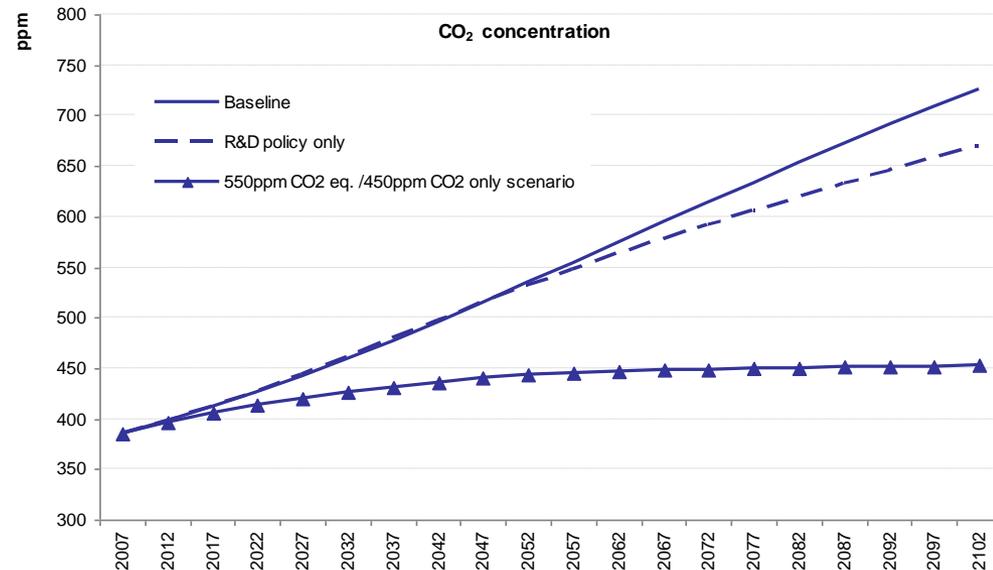
The impacts on mitigation costs are higher when the International Fund is used to finance the backstop technologies, but the magnitude is not large.

R&D subsidies to the backstop technologies as a stand alone policy

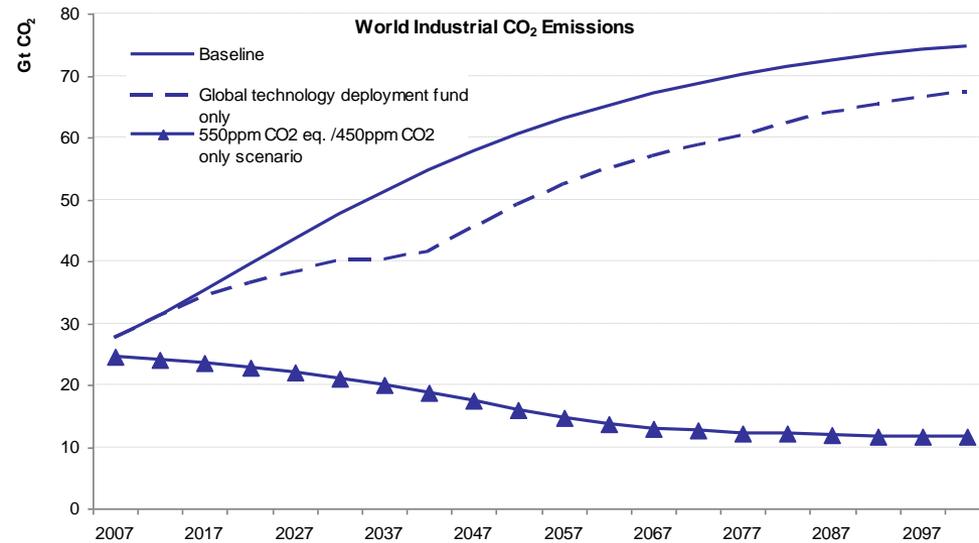


In the absence of a carbon price signal, the subsidies to backstop R&D stabilise emissions by mid-century. The effect on concentration is negligible because of inertia in the system.

Hence, limited environmental effectiveness, but *increase* in GWP → internalisation of knowledge externality

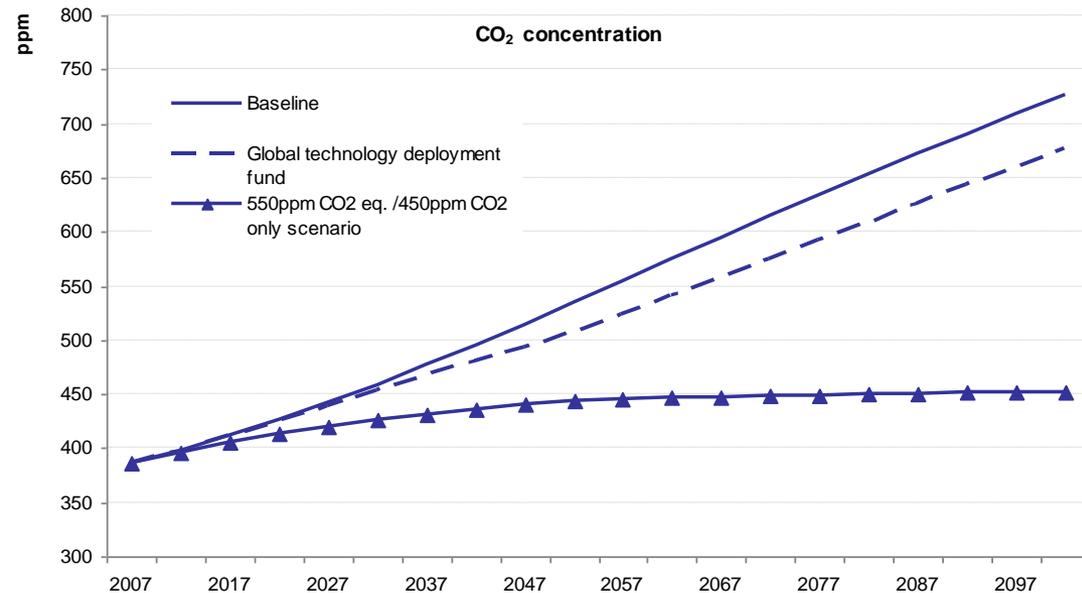


Global technology deployment subsidies as stand alone policy



...in the absence of a carbon price signal, subsidising deployment of existing technologies has a quicker impact on emissions...

...but the effect gradually fades out, and atmospheric concentration continue to increase.



R&D Cooperation and Climate Clubs

- Climate clubs crucially depend on the existence of excludable benefits for members or sanctions for non-members
- Given the low likelihood of trade sanctions to non-members, R&D investments and cooperation are important sources of excludable benefits
- I.e. an R&D club can provide important benefits to club members, benefits from which non-members can be excluded
- **Examples: patents available to club members only or joint R&D programs**

R&D, Finance and Climate Clubs

- R&D and innovation investments can therefore be used to provide multiple benefits:
 - Technological innovations without which the 2°C target cannot be achieved

and

- Incentives for climate club formation, which otherwise would not emerge

Incentives are crucial to achieve political willingness and therefore the resources for R&D and innovation development and diffusion

R&D Clubs: excludability

Two possible objections can be raised. **First, non-members cannot be fully excluded** from benefits stemming from R&D cooperation.

- R&D and knowledge spillovers, and lack of protecting patents and copyrights, may reduce the benefits that accrue to club members only.
- It is an empirical and regulatory matter to design patent schemes and disclosure rules enabling club members to exclude non-members, at least partly, from R&D cooperation benefits.

R&D Clubs: incentive compatibility

The **second** objection to the feasibility of an R&D climate club is that the decision to form the club, prompted by economic incentives stemming from R&D cooperation, **is itself a strategic decision** subject to free-riding.

The crucial questions are:

- Do countries have an incentive to link R&D cooperation and GHG emission reduction instead of developing R&D cooperation and innovation diffusion independently of the climate club?
- Or do they prefer to cooperate with a different (likely larger) number of countries if they cooperate only on innovation?

R&D Clubs: incentive compatibility

The answer to the two possible objections is provided in Carraro and Marchiori (2004), who show that:

- (i) if the degree of excludability of R&D cooperation benefits is sufficiently high; and
- (ii) if damages from climate change avoided by actions undertaken by club members are sufficiently large;

then there is the incentive to form a climate club in which members invest in R&D and cooperate to reduce GHG emissions.

Conclusions 1

- Technological change plays a key role in supporting the transition to a low-carbon economy
- Carbon pricing is an important stimulus to technological innovation, both in inducing higher investments in R&D and more deployment of existing low carbon technologies such as W&S and CCS
- Credibility of future climate change commitments and expectations about future carbon prices matter for today's investment decisions.

Conclusions 2

- Unlike trade-related policies intended to favor club members, R&D cooperation policies do not have negative “side effects” for member countries.
- Indeed, they provide positive “technological” co-benefits, in addition to the primary “environmental” benefits - a “double dividend” for club members, and a single dividend (GHG emission reduction) for the world.

Thank you!

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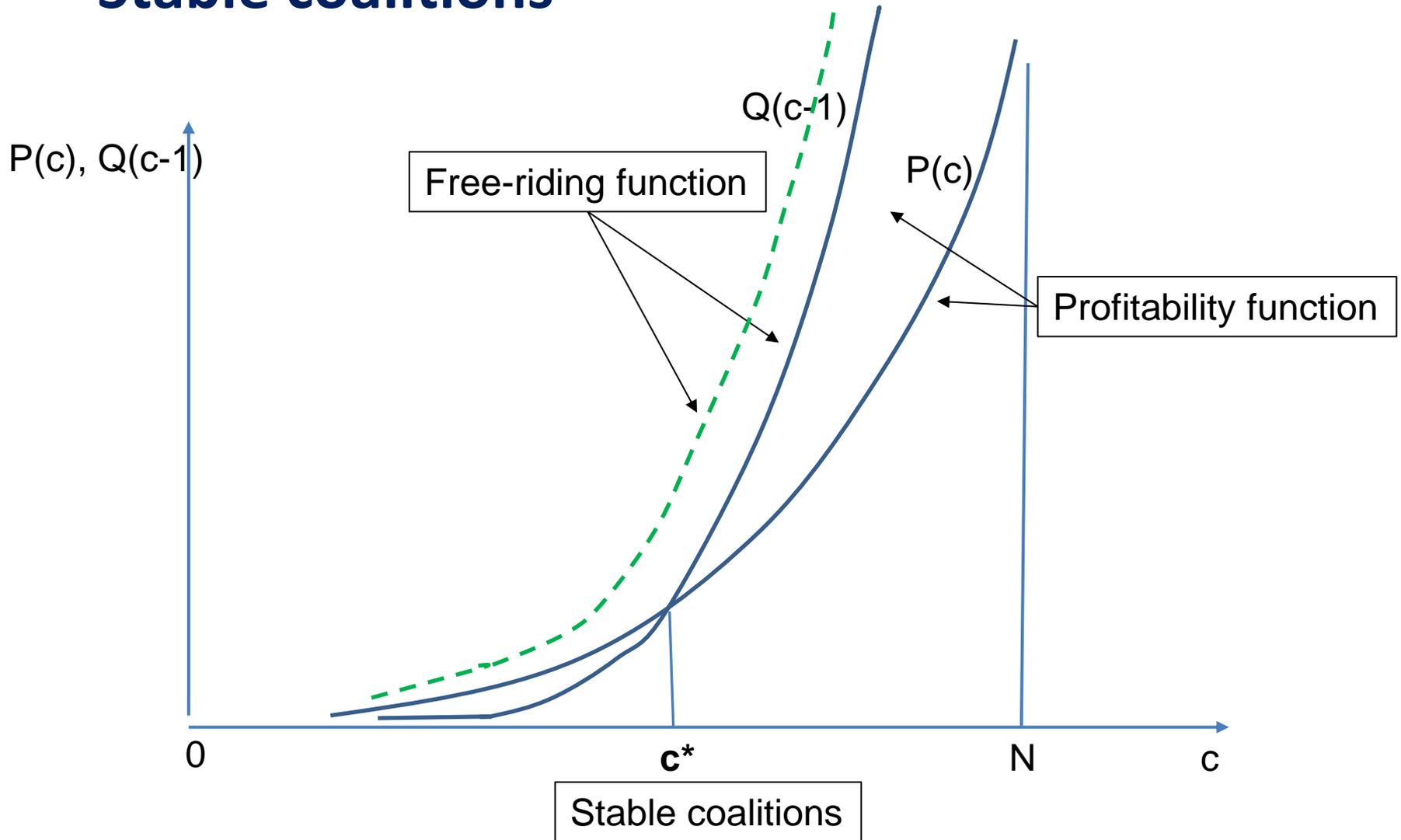
Backup slides



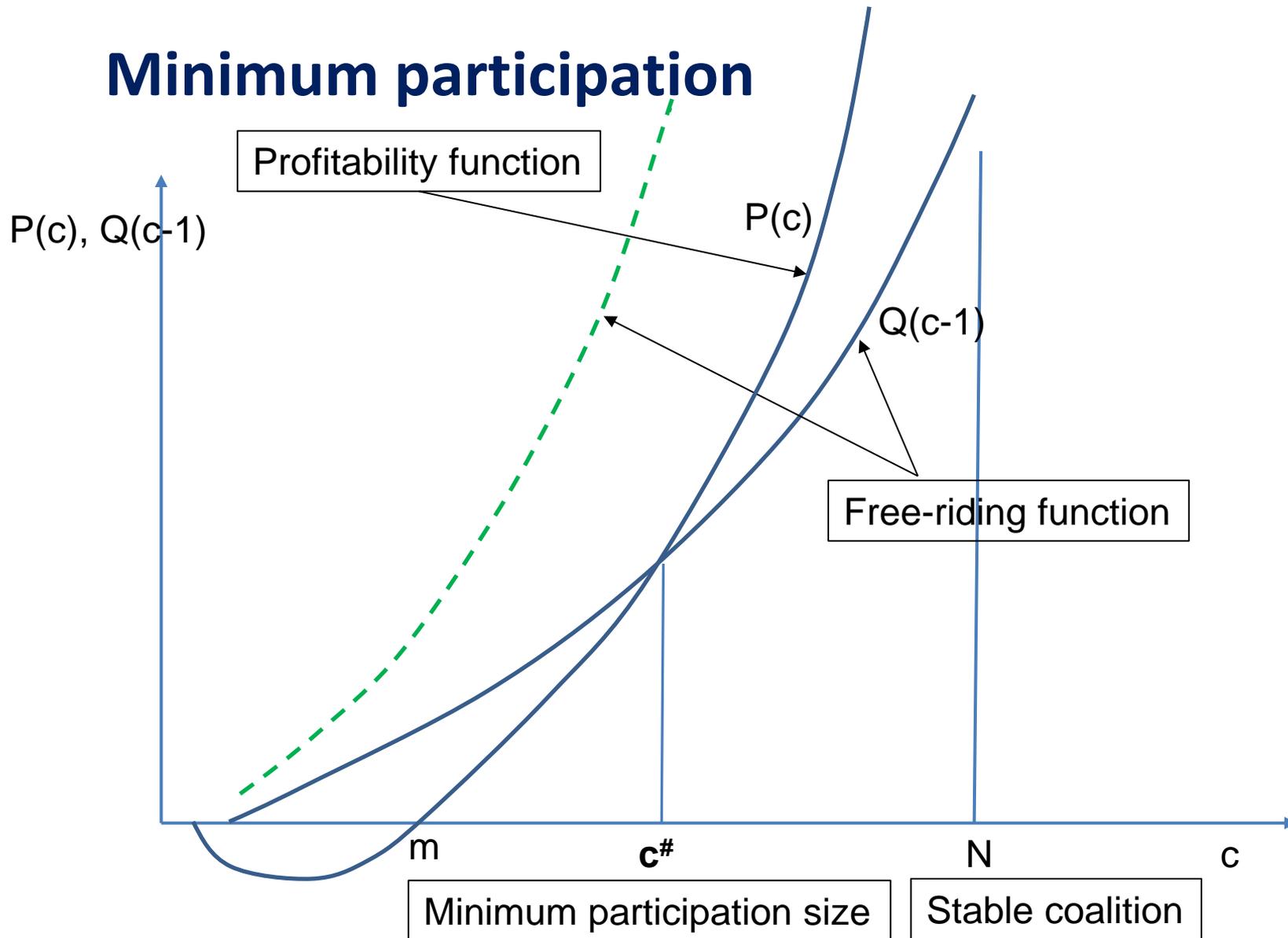
Research questions

- **How can technological innovation be stimulated?**  • Effects of carbon price signals, R&D subsidies, ...
- **What is the role of technological innovation in reducing stabilization costs?**  • Existing and new technologies, spillovers
- **Would a policy to further stimulate technological innovation be granted?**  • A Global International R&D Fund
- **Can technological innovation policies alone stabilize GHG concentrations?**  • Technological innovation as stand alone policy
- **How can R&D cooperation and innovation investments affect the governance of climate change**  • Club of the willing for ambitious GHG emission reductions

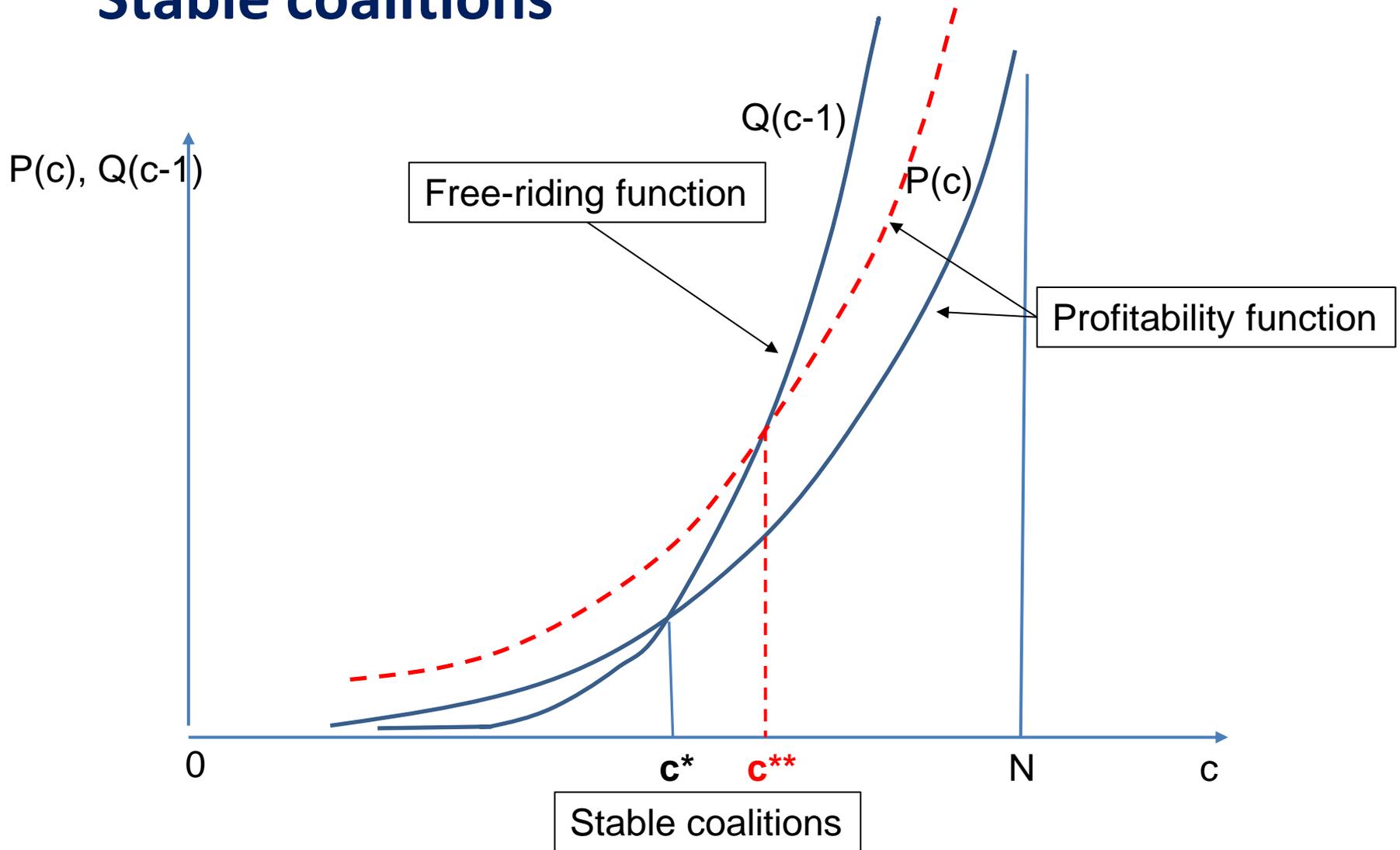
Stable coalitions



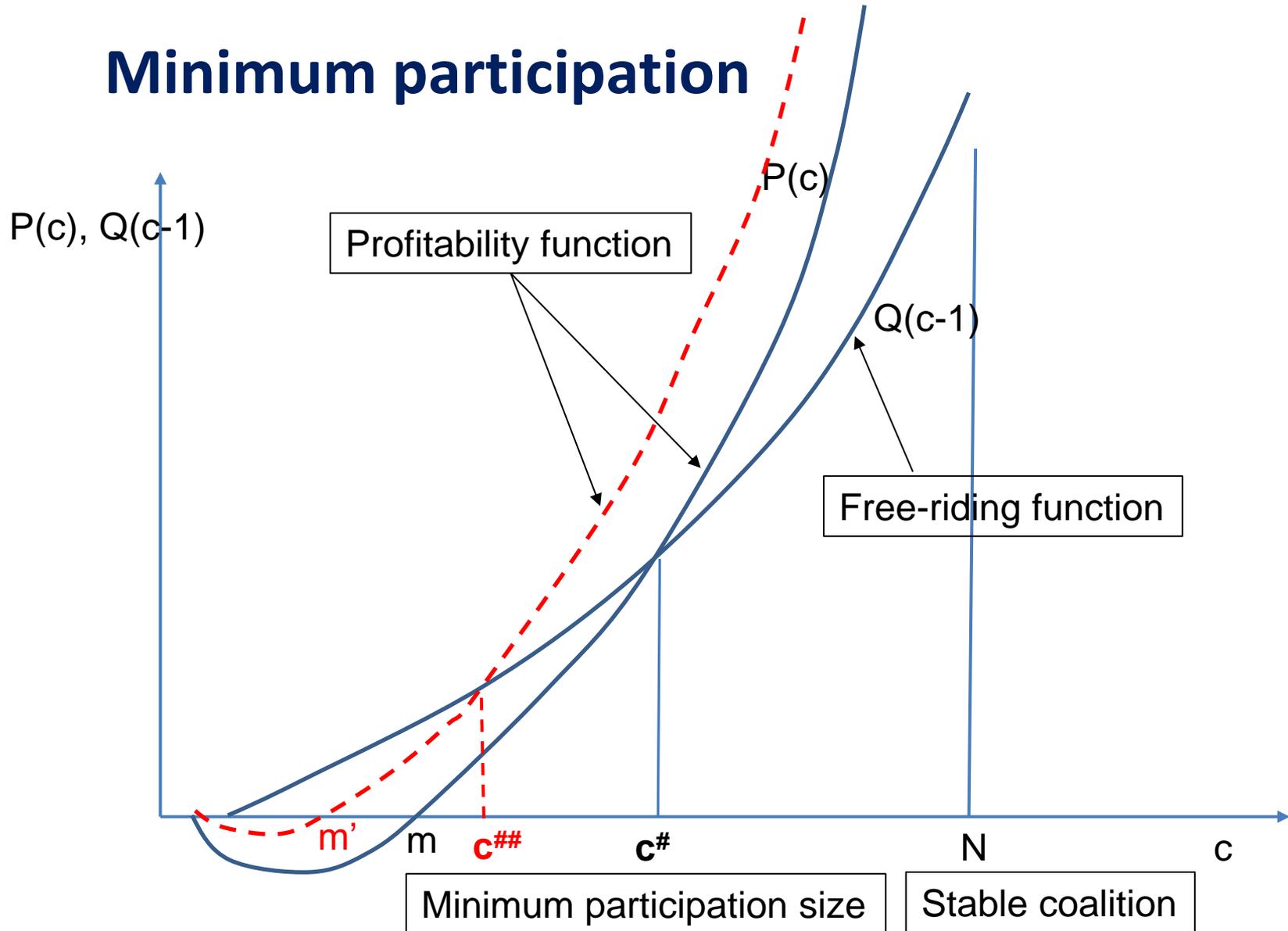
Minimum participation



Stable coalitions



Minimum participation



3. Non-OECD countries are becoming important in R&D

China example

- Energy spread across ministries
 - Just in Ministry of S&T, energy receives about 10%, \$1 bn
- Out of at least 1000 public R&D centers, 17% focus on energy
- Changes in program management, role of scientists

