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CENTRE
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DE RECHERCHE
SUR L'ENVIRONNEMENT
ET LE DÉVELOPPEMENT

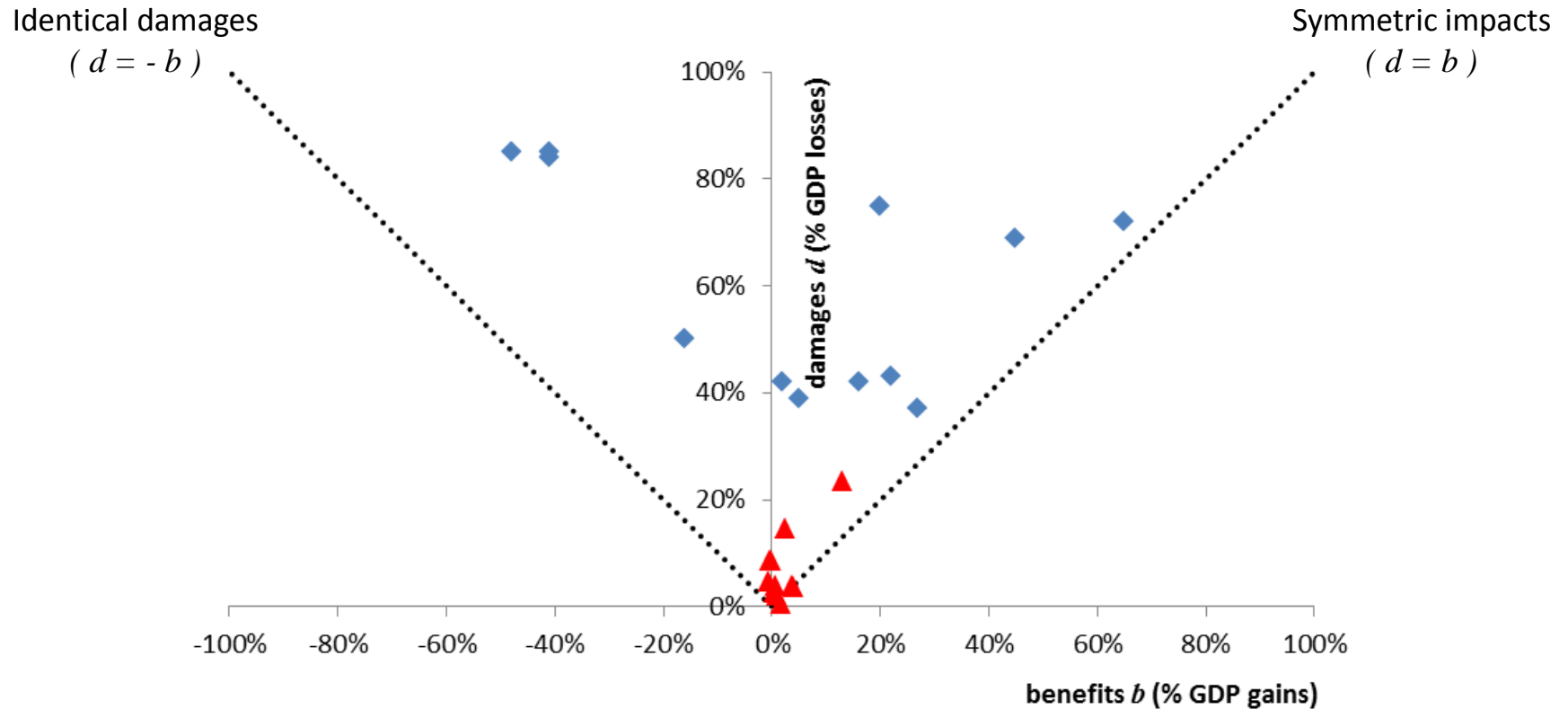
Global warming as an asymmetric public bad

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A Toxa – June 27, 2016

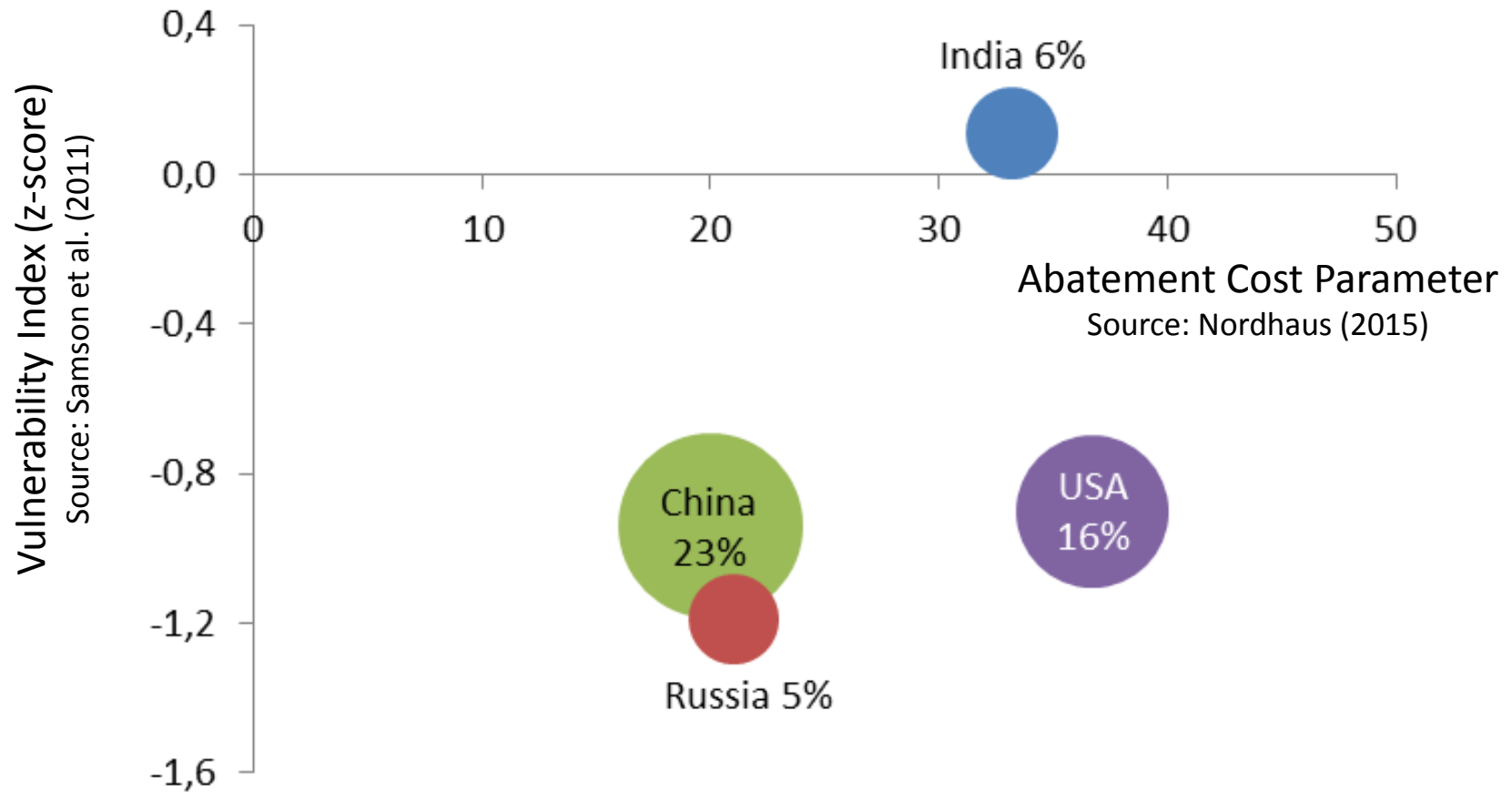
Global warming has asymmetric impacts



◆ Burke et al. (2015): impact by 2100, median gainer vs. median loser

▲ Tol (2009): Impact for 2-3°C, best-off vs. worst-off region

Adaptation and mitigation little correlate



?: share of 2010 global GHG emissions

Source: WRI (2014)

Adaptation may exacerbate warming

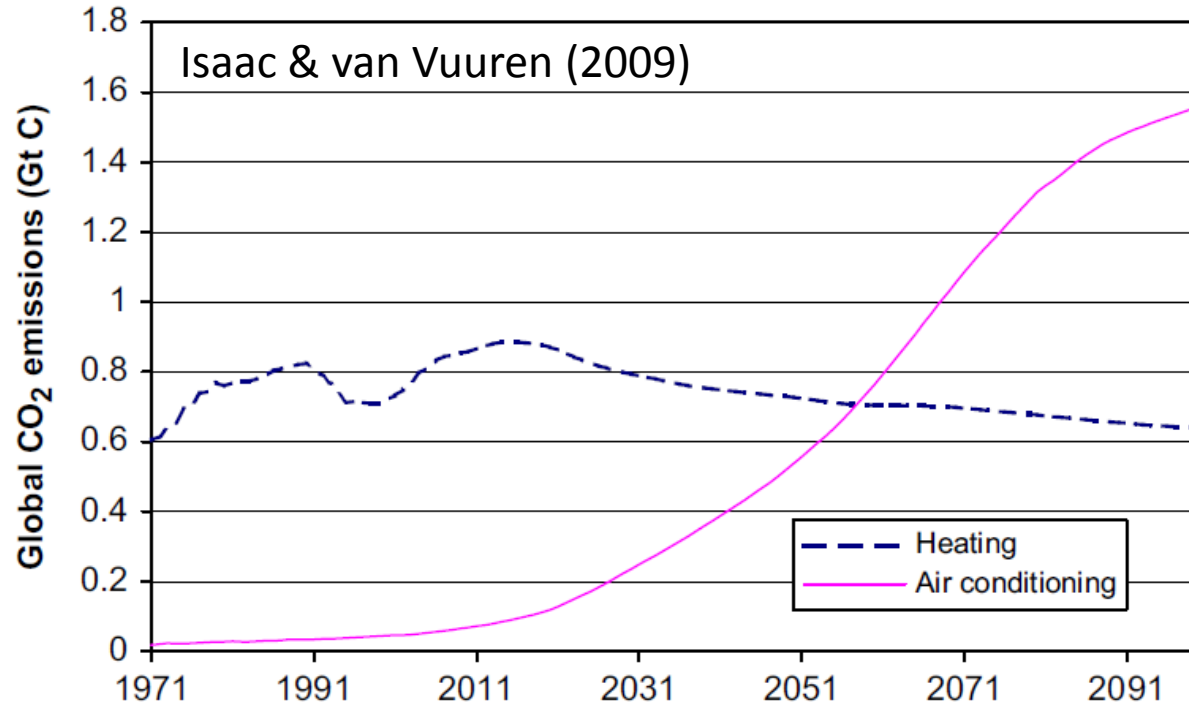


Fig. 7. Modeled global CO₂ emissions from heating and from air conditioning in the residential sector (reference scenario).

- Growing concerns about the warming potential of air conditioning (*Barrecca et al., 2016; Davis and Gertler, 2015; Auffhammer and Mansur, 2014*).
- At least conceptually, agriculture could also be a concern (fertilizers, irrigation).

- ***We extend the canonical dynamic game of global warming to capture three stylized facts***
 1. Asymmetric impacts (gainers & losers)
 2. Correlations between adaptation and mitigation capabilities
 3. Warming potential of adaptation (“free-driving”)

- ***We examine the policy implications of those asymmetries for***
 - “Bottom-up” approaches: e.g., US-China Agreement, NDCs
 - Optimal solutions: GHG emission pricing

- ***We contribute to opening up the public good model, besides***
 - Kotchen’s “impure public goods” (2005)
 - Nordhaus’ “climate clubs” (2015)

Dynamic Games of Global Warming: Background

- Mitigation
 - Prevailing structure: Linear-quadratic in state, identical players.
 - Discussion of open-loop vs. feedback non-cooperative strategies (*van der Ploeg & de Zeeuw, 1992; Hoel, 1993*)
 - With small enough discount rate, non-linear feedback can induce too little warming (*Dockner and Long, 1993*). Restrictions subsequently placed on the result (*Rubio and Casino, 2002; Wirl, 2007*)
 - Partial account of heterogeneity (*Martin et al., 1993; Zagonari, 1998*)
 - Adaptation
 - Mitigation in period 1, adaptation in period 2 (*Buob and Stephan, 2011; Ingham et al., 2013*)
 - Discussion of the private/public aspects of adaptation (*Mendelsohn, 2000*), but not of its implications for warming
- **Missing:**
- **Full characterization of asymmetry of impacts**
 - **Full integration of mitigation and (potentially emitting) adaptation**

A 2-player Model of Space Heating and Cooling

cold region



Mitigation in the cold region (q^c)

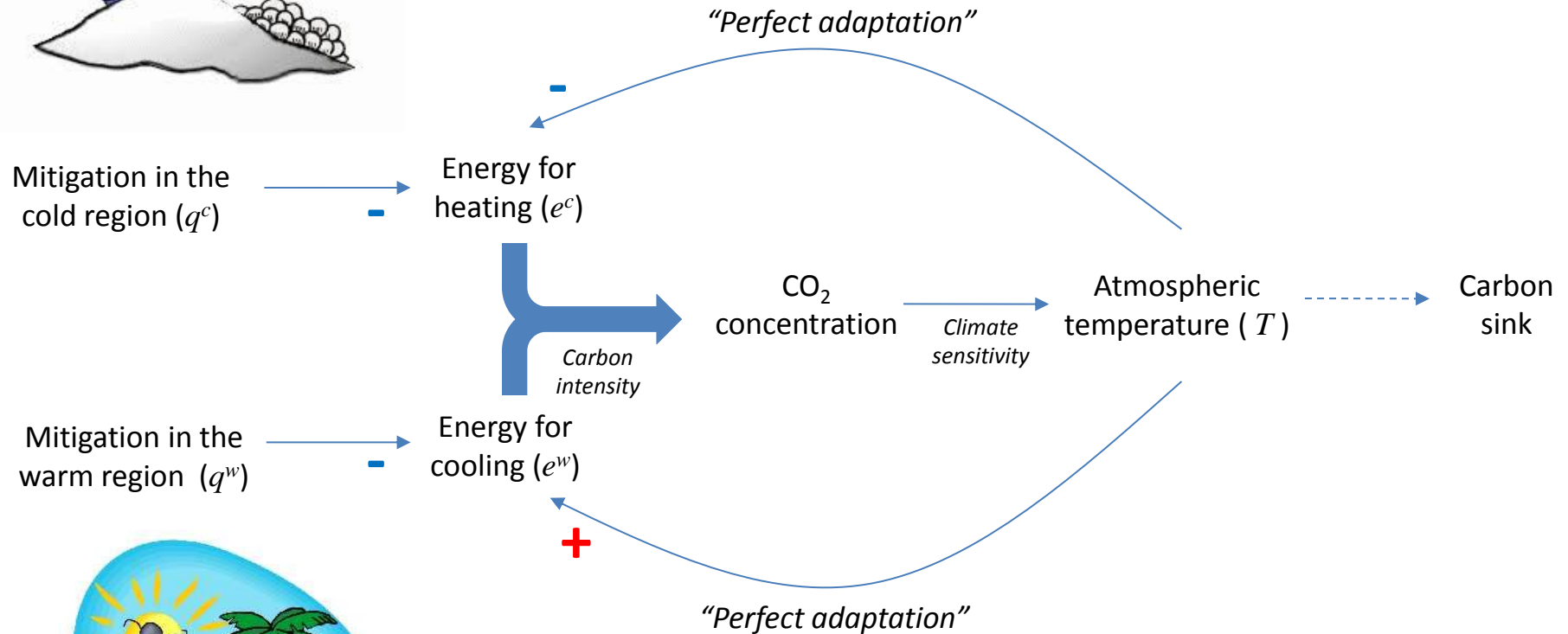
Energy for heating (e^c)

Mitigation in the warm region (q^w)

Energy for cooling (e^w)



warm region



“Adaptive Mitigation”

Energy use

$$e^c(q, T) \equiv \varepsilon - q - bT$$

Controlled mitigation
(energy/carbon efficiency)

“Perfect” adaptation to
asymmetric, linear impacts

$$e^w(q, T) \equiv \varepsilon - q + dT$$

Technology

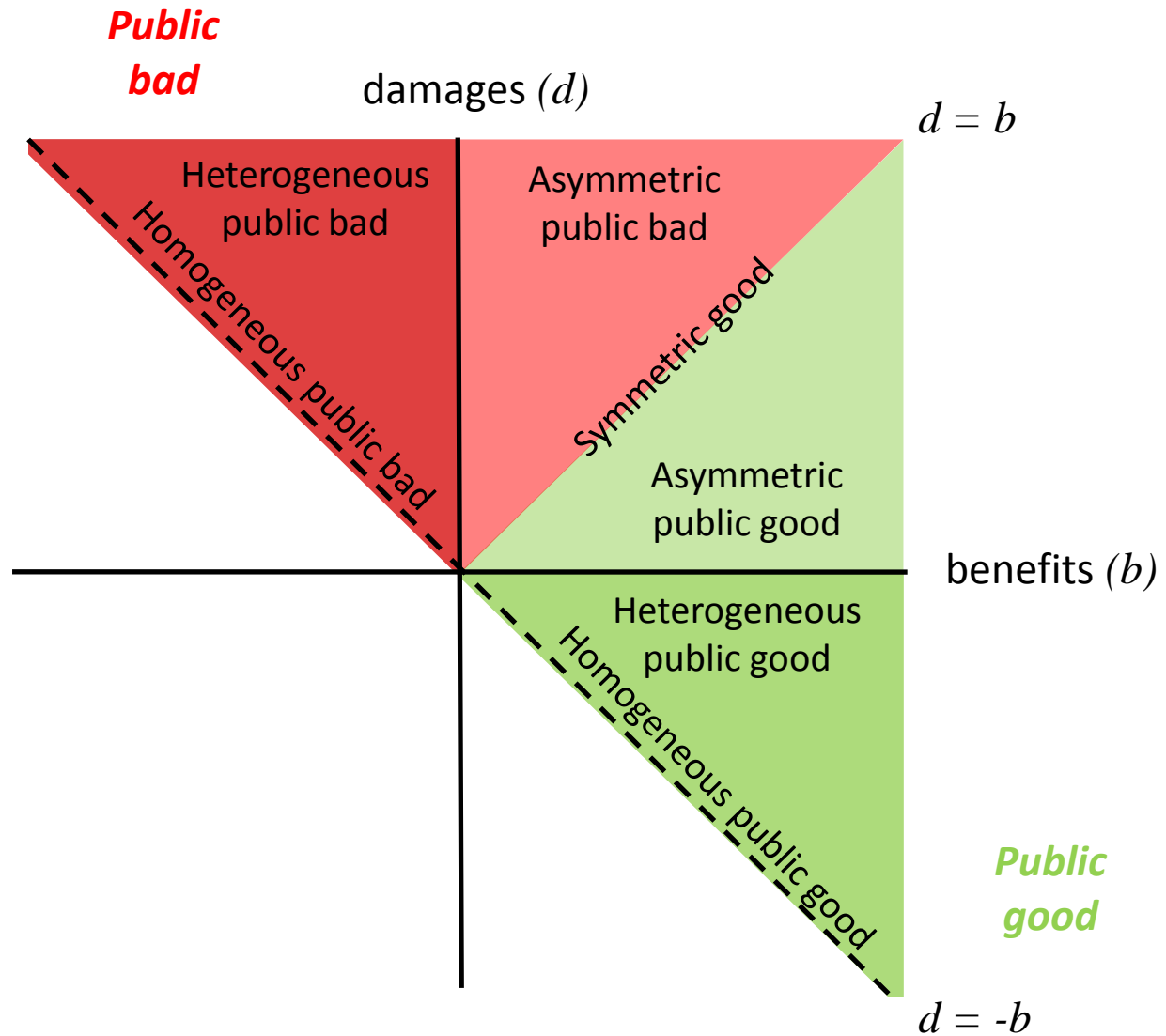
$$\forall i \in \{c, w\} \quad m^i(q) \equiv \gamma^i q^2 / 2$$

Warming

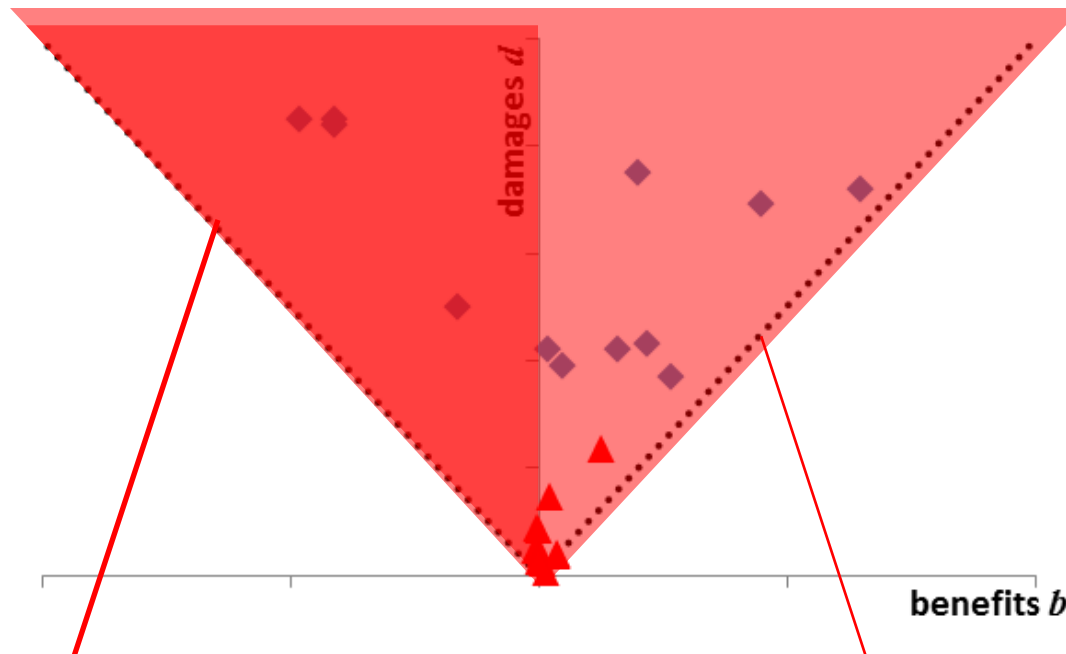
$$\dot{T} = e^c(q^c, T) + e^w(q^w, T) - \underbrace{sT}_{\text{Natural sink}}$$

Retroaction

Taxonomy of Public Goods



Focus on the Public Bad Corner ($d > |b|$)



*Usually studied:
homogeneous & heterogeneous public bad*

*Our study:
More general public bad (incl. asymmetric)*

Optimization Problems

$$\begin{array}{c}
 \text{Energy} \quad \text{Mitigation} \\
 \text{expenditure} \quad \text{cost} \\
 \text{Minimize}_{q^c, q^w} \quad \Gamma_i \equiv \int_0^\infty \underbrace{e^i(q^i, T)}_{\text{Energy expenditure}} + \underbrace{m(q^i)}_{\text{Mitigation cost}} e^{-rt} dt \\
 \text{subject to } \dot{T} = e^i(q^i, T) + e^{-i}(q^{-i}, T) - sT
 \end{array}$$

Cooperative

$$\mathcal{H} \equiv \left(\sum_i \right) [e^i(q^i, T) + m(q^i)] - \lambda [e^i(q^i, T) + e^{-i}(q^{-i}, T) - sT]$$

Non-coop.,
fwd-looking

$$\mathcal{H}^i \equiv [e^i(q^i, T) + m(q^i)] - \lambda^i [e^i(q^i, T) + e^{-i}(q^{-i}, T) - sT]$$

Non-coop.,
myopic

$$\mathcal{F}^i \equiv e^i(q^i, T) + m(q^i)$$

Optimality Conditions

Stable steady state $\left(\frac{d\dot{T}}{dT}\right)_{T^\infty} < 0 \Rightarrow s > d - b$

Optimal mitigation $d\mathcal{H}^i/dq^i = 0 \Rightarrow q^i = (1 - \lambda^i)/\gamma^i$

Co-state Dynamics

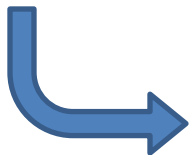
$\dot{\lambda} - r\lambda = -d\mathcal{H}^i/dT \Rightarrow \dot{\lambda} = (r + b - d + s)\lambda - b + d$ Cooperative (social optimum)

$$\begin{cases} \dot{\lambda}^c = (r + b - d + s)\lambda^c - b \\ \dot{\lambda}^w = (r + b - d + s)\lambda^w + d \end{cases}$$
 Forward-looking (Nash equilibrium)

T is absent \rightarrow Open-loop and feedback coincide, ensuring subgame perfectness

Co-state Variables at Steady State

$$\begin{cases} \dot{\lambda} = 0 \\ d > b \end{cases}$$



Social optimum (S)

$$\lambda = \frac{-d + b}{r + s + b - d}$$

Global public **bad**

Nash (N)

$$\begin{cases} \lambda^c = \frac{b}{r + s + b - d} > 0 \\ \lambda^w = \frac{-d}{r + s + b - d} < 0 \end{cases}$$

(small) local
public **good**

(large) local
public **bad**

Myopic (M)

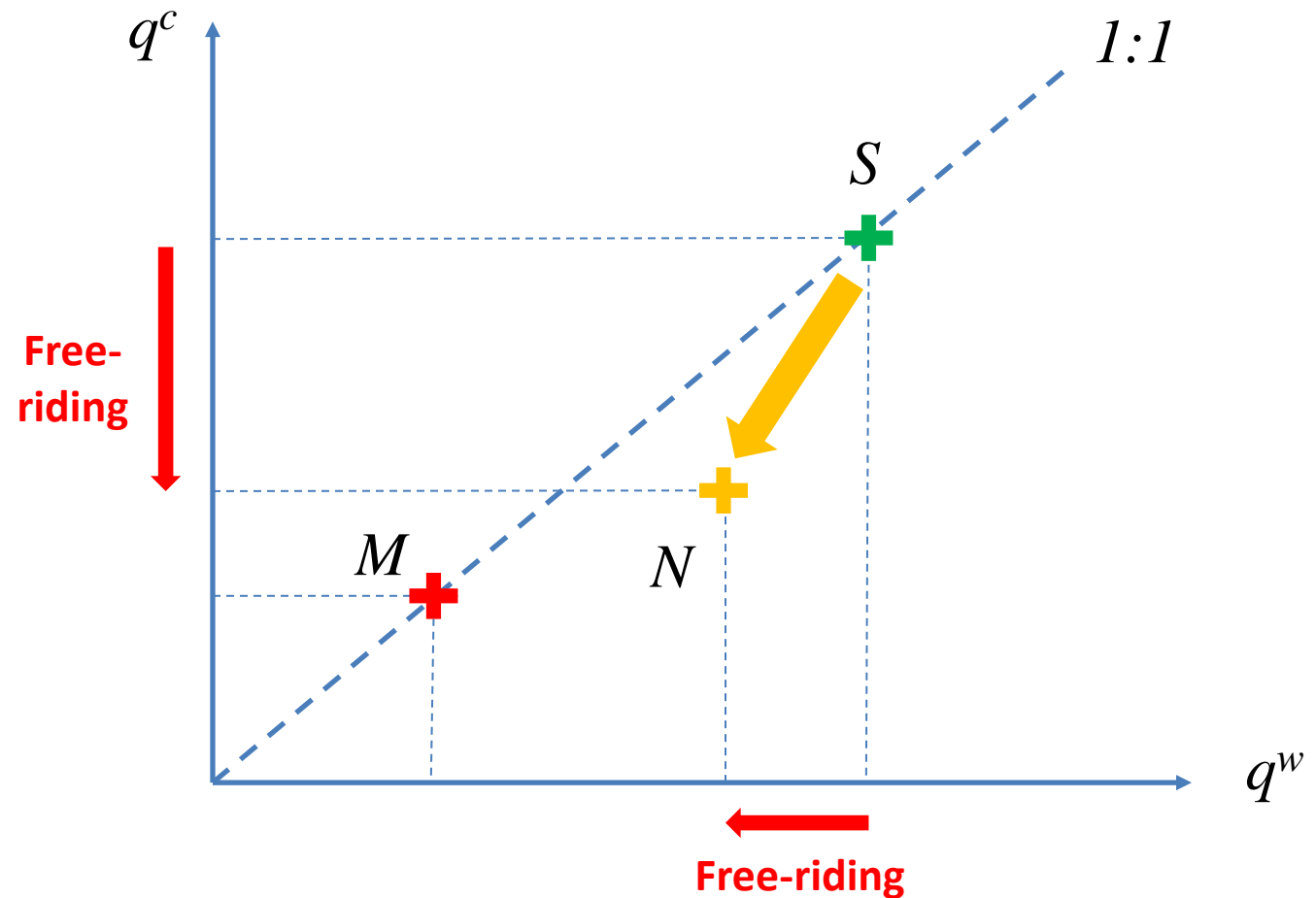
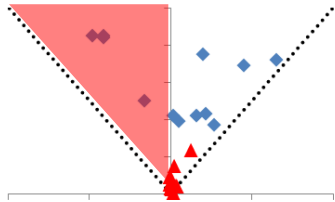
$$\lambda \equiv 0$$

Not shown here: Co-state variables (hence mitigation efforts) are STATIONARY

Heterogeneous Public Bad (*canonical – both lose*)

Assumptions

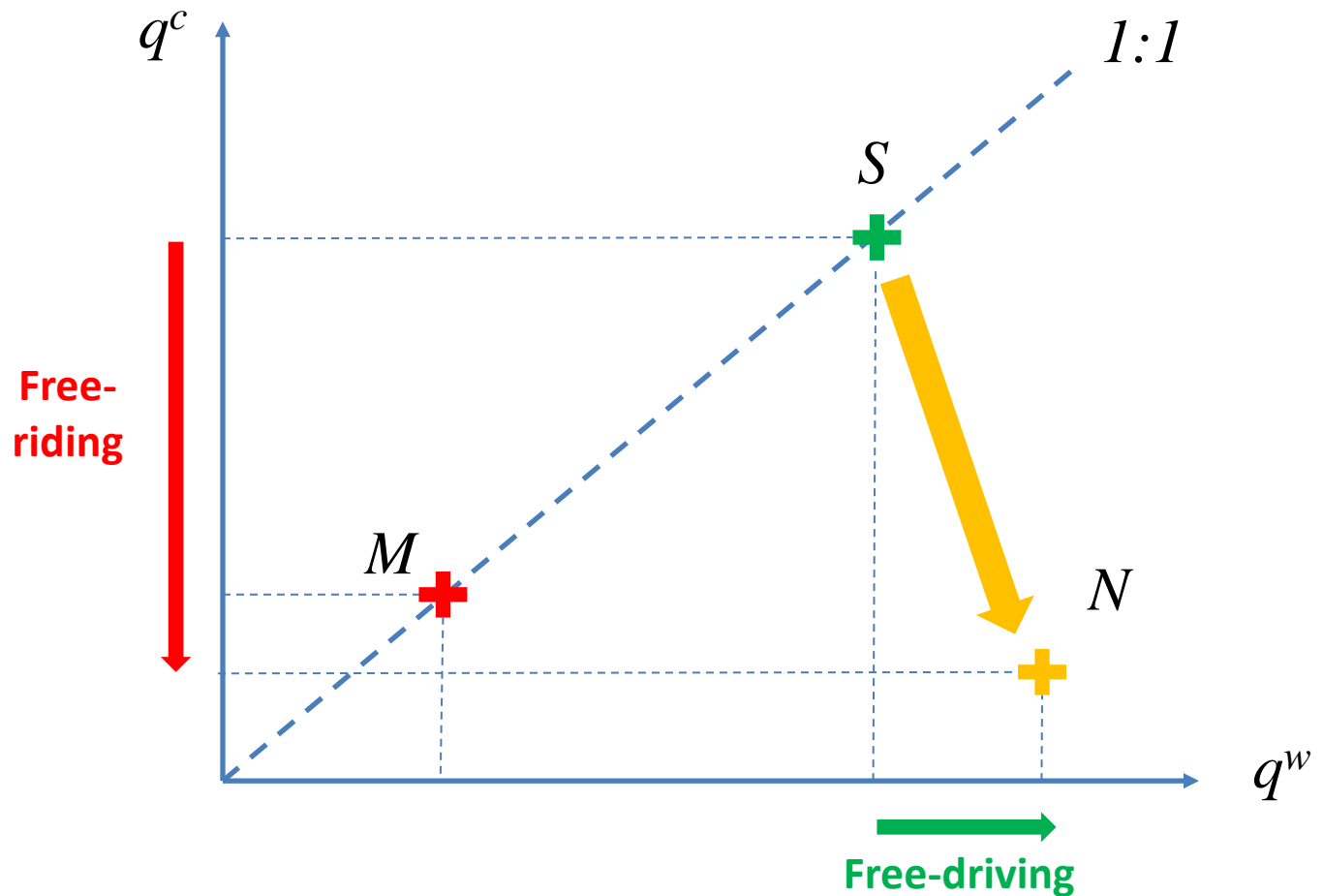
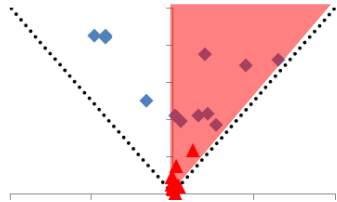
$$\begin{cases} \gamma^c = \gamma^w \\ d > -b > 0 \end{cases}$$



Asymmetric Public Bad (= *gainer & loser*)

Assumptions

$$\begin{cases} \gamma^c = \gamma^w \\ d > b > 0 \end{cases}$$



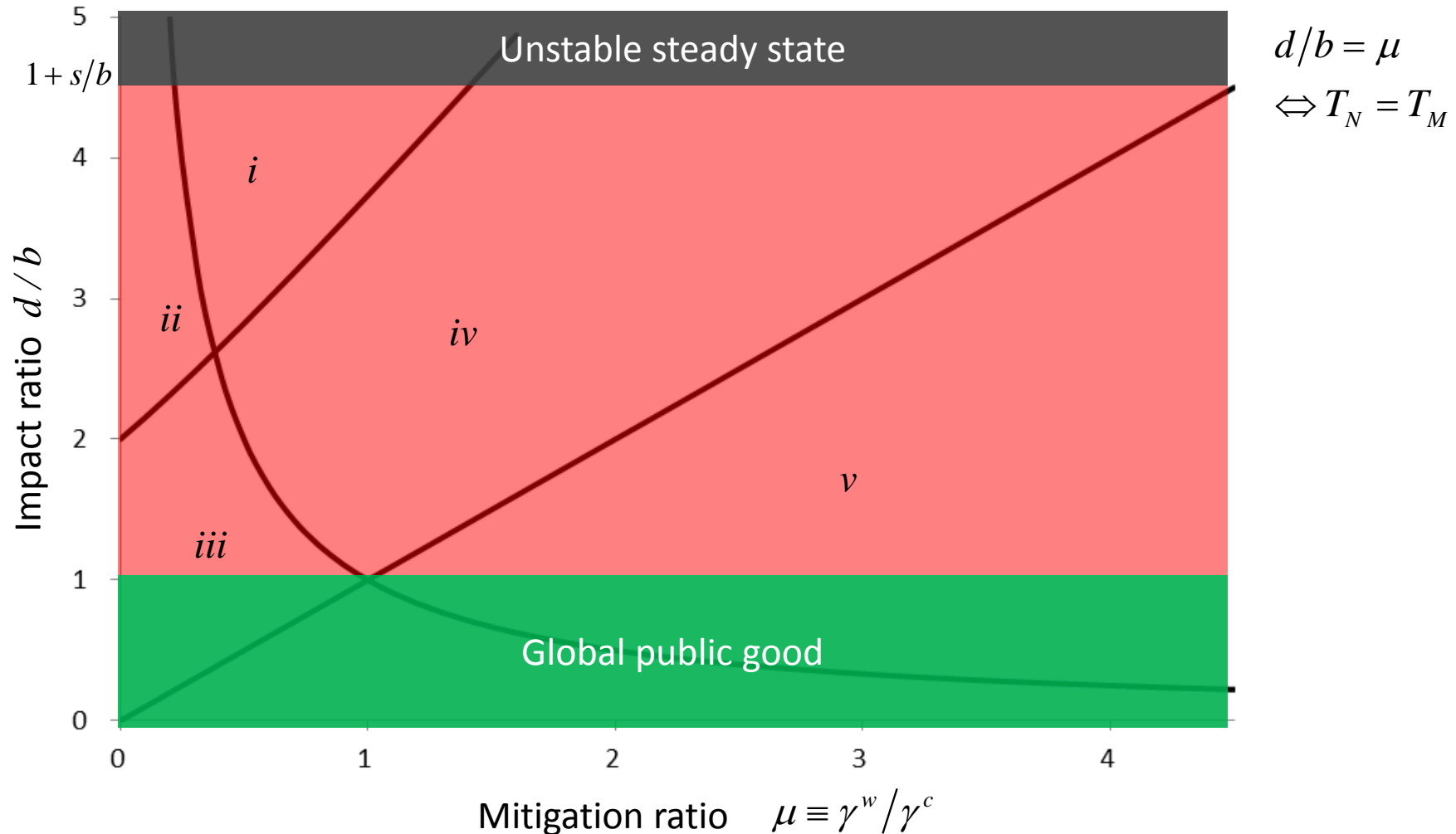
Five Regimes of Asymmetric Public Bad ($d > b > 0$)

$$d/b = 1/\mu$$

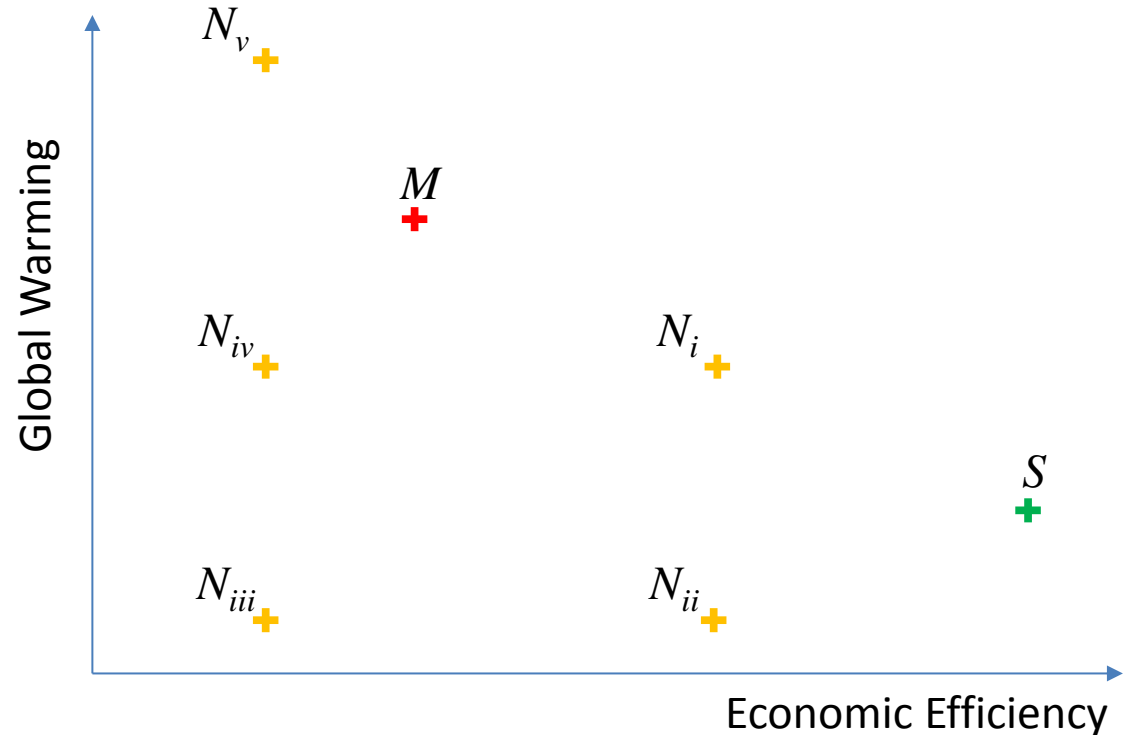
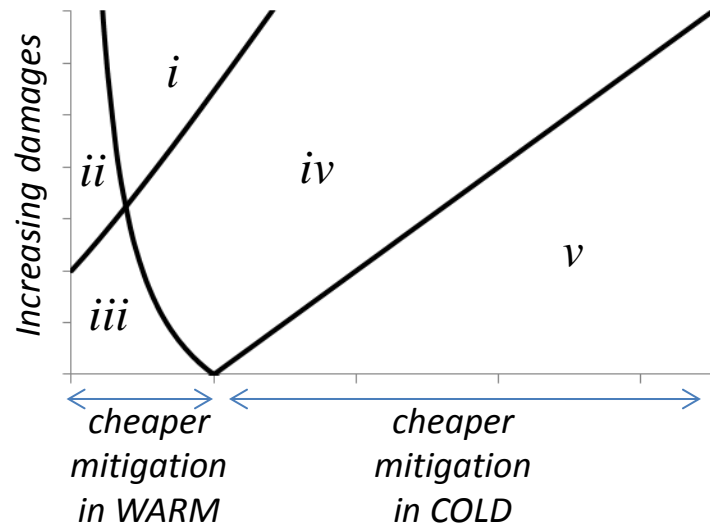
$$\Leftrightarrow T_N = T_S$$

$$d/b = 1 + \mu + \sqrt{1 + \mu + \mu^2}$$

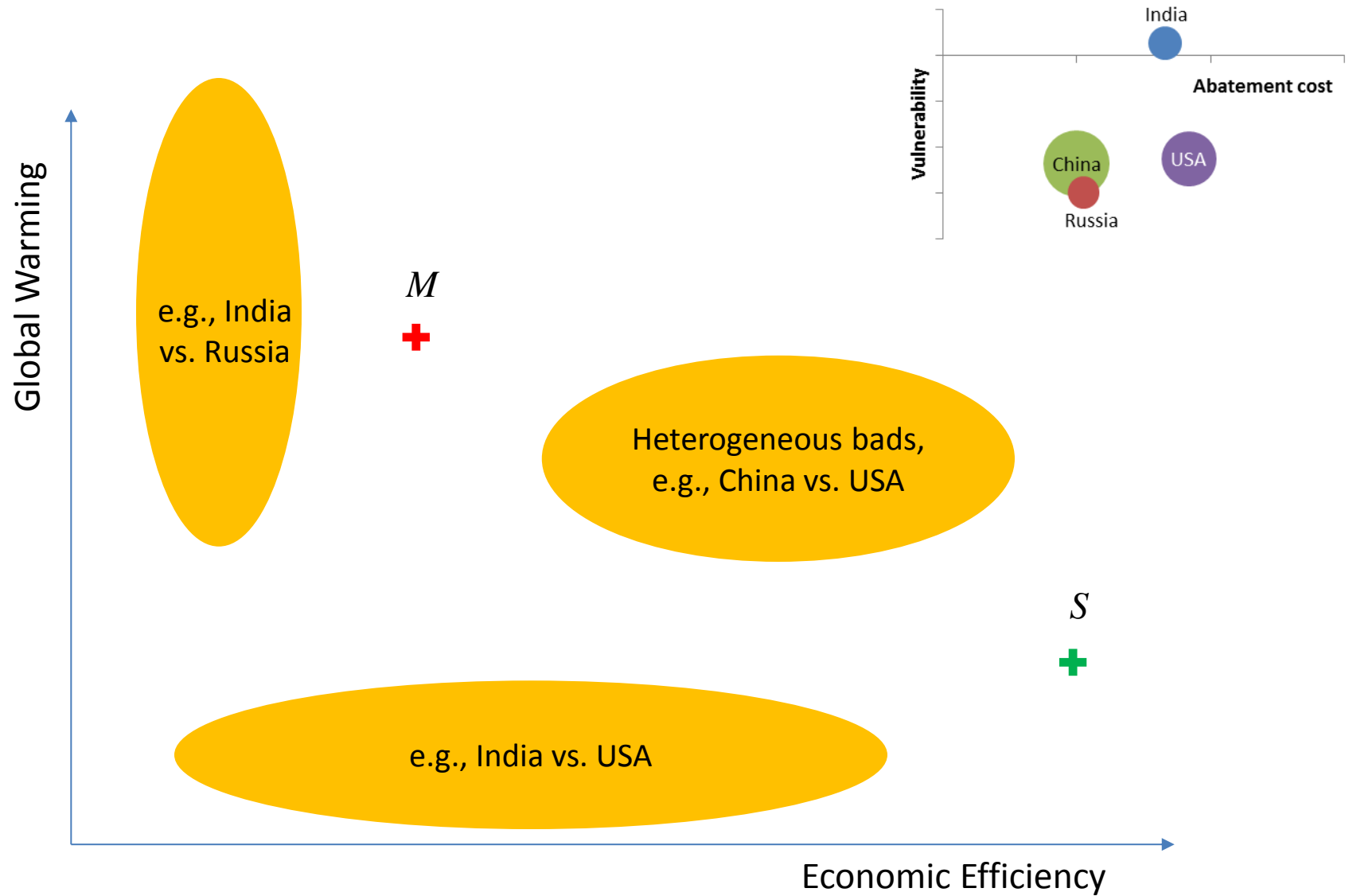
$$\Leftrightarrow \Gamma_N = \Gamma_M$$



Efficiency-Warming Tradeoffs

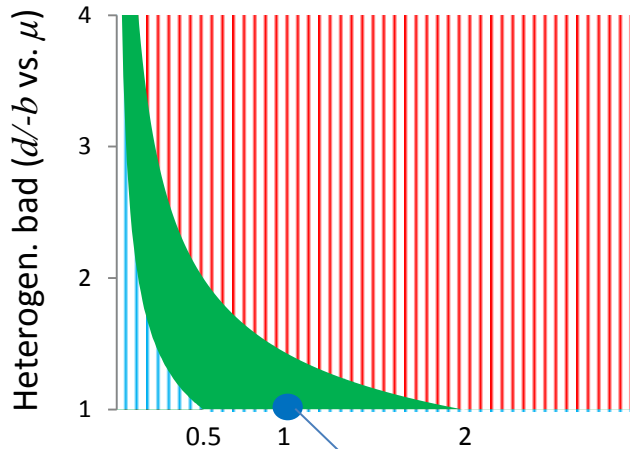


Interpretation: Bilateral Agreements

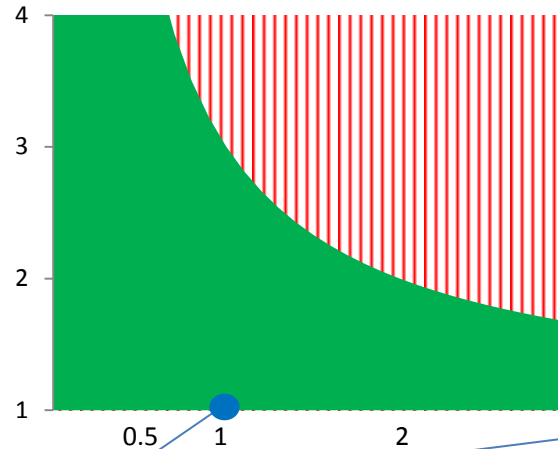


Welfare Improvements

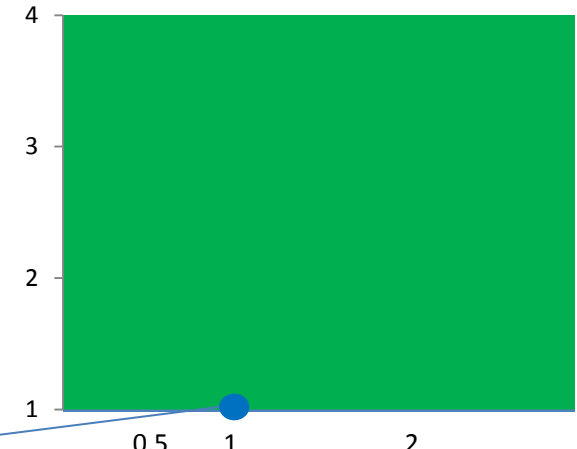
Nash \rightarrow Social optimum



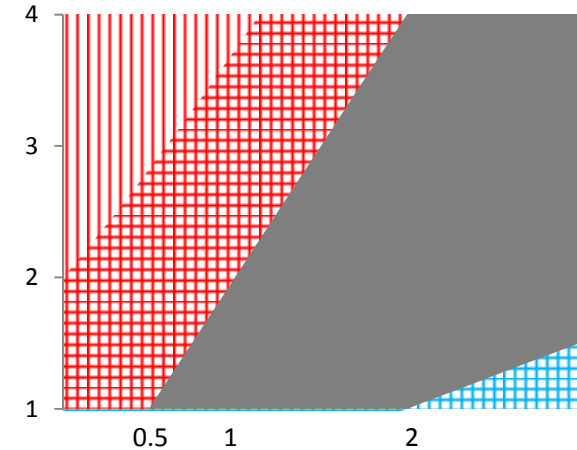
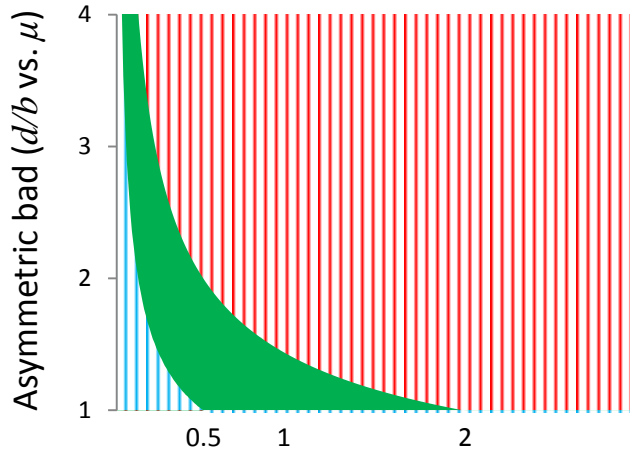
Myopia \rightarrow Social optimum



Myopia \rightarrow Nash



Homogeneous bad (canonical)



Pareto:
c and w gain

Hicks-Kaldor:
c gains, w loses

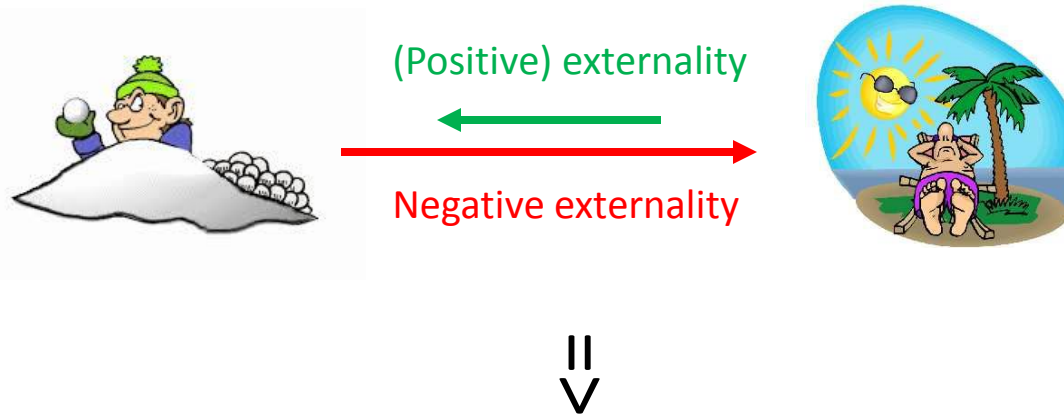
Hicks-Kaldor:
w gains, c loses

c gains,
w loses

w gains,
c loses

c and w lose

Optimal Pigouvian Prices (p_k^i)



$$p_k^i = \frac{\lambda_k^i - \lambda}{1 - \lambda_k^i}$$

Two externalities necessitate two prices

UNLESS

the players are myopic ($\lambda_M^i = 0$) or identical ($\lambda_M^c = \lambda_M^w$)

Taking into account asymmetries in adaptation and mitigation, we find

- Conditions under which a dynamic public bad can be under-supplied
- Restrictions on Pareto improvements (esp. $M \succ N$)
- A case for differentiated emission prices, which can include (small) subsidies for GHG-intensive adaptation

Discussion

- Climate change restricted to *smooth warming*
 - No sea level rise, ocean acidification, etc.
 - No stochastic events, catastrophes, etc.
- Linear-state structure
 - Pertinent at the global scale, less at the local one (e.g., Dell et al., 2014)
 - Flexibility of open loop & strength of feedback (subgame perfectness)
- Specific technology
 - Emissions induced by adaptation: what potential?
 - No accumulation of mitigation capital
- ***Our model is therefore most relevant to***
 - ✓ ***Large countries (China + USA ~ 40% of global emissions)***
 - ✓ ***Sectors such as buildings, agriculture (resp. 6% and 24% of emissions)***
 - ✓ ***Short-term, moderate impacts***

The New York Times

December 13, 2013

British Wine Benefits as the Climate Changes

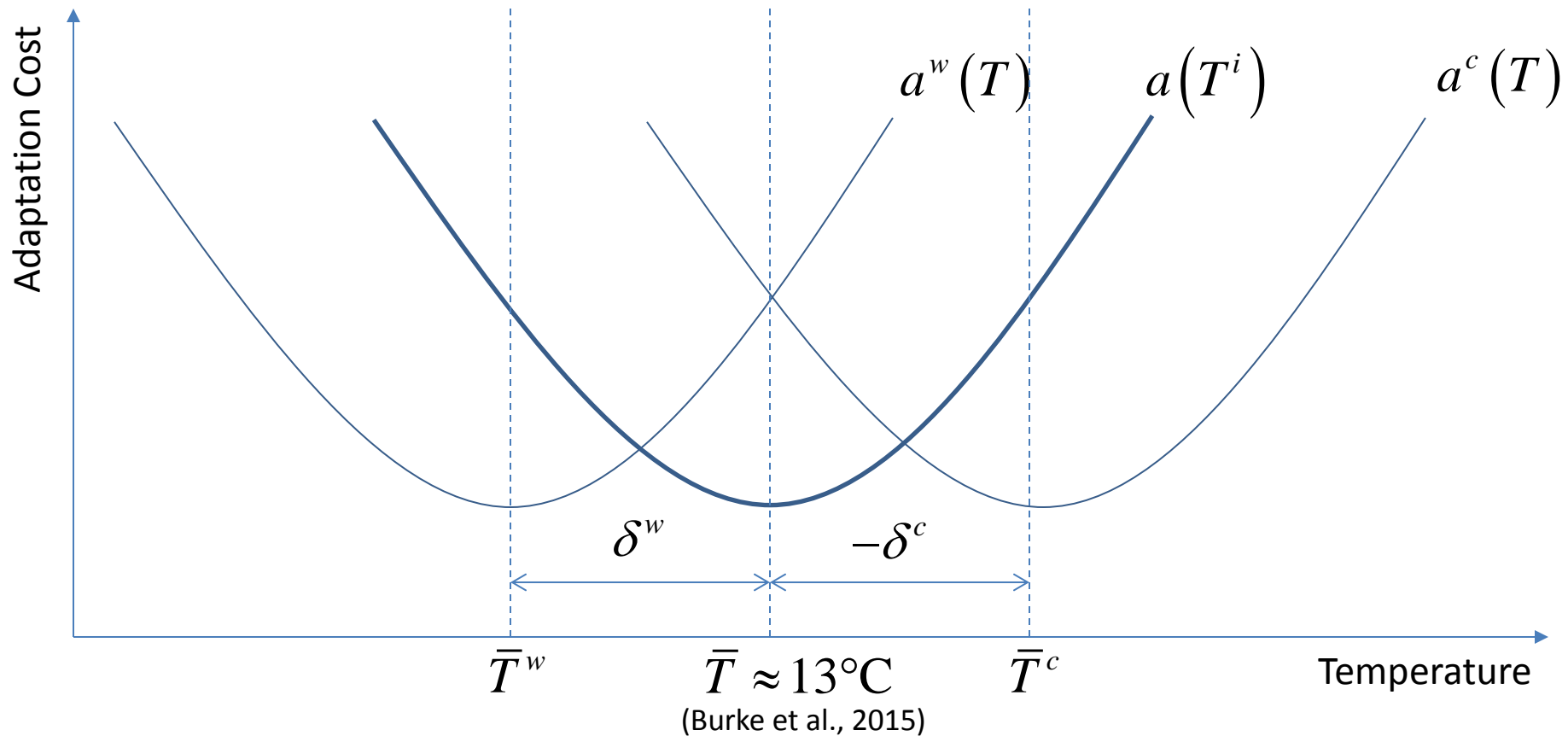
By GEORGI KANTCHEV

DORKING, England — For more than a decade, Matthieu Elzinga ran his own vineyard in the western Loire Valley of France. But this year, just as he was gaining an international reputation for his dry and crisp Muscadets, Mr. Elzinga sold the vineyard and moved to an emerging wine region: the south of England.

Extension: Non-linear Adaptation

$$a(T^i) \equiv (T^i - \bar{T})^2$$

$$\Leftrightarrow a^i(T) \equiv (T - \bar{T}^i)^2 \quad \text{with} \quad \begin{cases} T^i \equiv T + \delta^i \\ \bar{T}^i \equiv \bar{T} - \delta^i \end{cases}$$



Heterogeneous Public Good

Asym. PG

Asym. PB

Heterogeneous Public Bad

Quadratic-State Model

Adaptation

$$a^i(T) \equiv (T - \bar{T}^i)^2$$

Energy use

$$e^i(q, T) \equiv \varepsilon - q - a^i(T)$$

Technology

$$\forall i \in \{c, w\} \quad m^i(q) \equiv \gamma^i q^2 / 2$$

Warming

$$\dot{T} = e^c(q^c, T) + e^w(q^w, T) - sT$$



Non-linear payoff function → Open-loop and feedback no longer coincide
Non-linear transition equation → Numerical resolution (Kossioris et al., 2008)

	Nash equilibrium	Social optimum	Myopic equilibrium
	$k = N$	$k = S$	$k = M$
λ_k^c	$\frac{b}{r+b-d+s}$	$\frac{-(d-b)}{r+b-d+s}$	0
λ_k^w			
$q_k^c = \frac{1-\lambda_k^c}{\delta^c}$	$\frac{1}{\delta^c} \frac{r-d+s}{r+b-d+s}$	$\frac{1}{\delta^c} \frac{r+s}{r+b-d+s}$	$\frac{1}{\delta^c}$
$q_k^w = \frac{1-\lambda_k^w}{\delta^w}$	$\frac{1}{\delta^w} \frac{r-d+s}{r+b-d+s}$	$\frac{1}{\delta^w} \frac{r+s}{r+b-d+s}$	$\frac{1}{\delta^w}$
	Decentralization	Decentralization	Decentralization
	$j = S - N$	$j = S - M$	$j = N - M$
$\Delta_j T^\infty = \frac{-\Delta_j q^c - \Delta_j q^w}{b-d+s}$	$\frac{\delta^c b - \delta^w d}{\delta^c \delta^w (r+b-d+s)(b-d+s)}$	$\frac{-(d-b)(\delta^c + \delta^w)}{\delta^c \delta^w (r+b-d+s)(b-d+s)}$	$\frac{\delta^w b - \delta^c d}{\delta^c \delta^w (r+b-d+s)(b-d+s)}$
$\Delta_j \Gamma^c = \frac{-\Delta_j q^c + \Delta_j [(q^c)^2] \delta^c / 2}{r} - \frac{b(b-d+s) \Delta_j T^\infty}{r+b-d+s}$	$\frac{\delta^w d^2 - 2\delta^c b^2}{2r \delta^c \delta^w (r+b-d+s)^2}$	$\frac{(d-b)(\delta^w (b+d) + 2b\delta^c)}{2r \delta^c \delta^w (r+b-d+s)^2}$	$\frac{-b^2 \delta^w + 2bd\delta^c}{2r \delta^c \delta^w (r+b-d+s)^2}$
$\Delta_j \Gamma^w = \frac{-\Delta_j q^w + \Delta_j [(q^w)^2] \delta^w / 2}{r} + \frac{d(b-d+s) \Delta_j T^\infty}{r+b-d+s}$	$\frac{\delta^c b^2 - 2\delta^w d^2}{2r \delta^c \delta^w (r+b-d+s)^2}$	$\frac{-(d-b)(\delta^c (b+d) + 2d\delta^w)}{2r \delta^c \delta^w (r+b-d+s)^2}$	$\frac{-d^2 \delta^c + 2bd\delta^w}{2r \delta^c \delta^w (r+b-d+s)^2}$
$\Delta_j \Gamma^{c+w} = \Delta_j \Gamma^c + \Delta_j \Gamma^w$	$\frac{-\delta^w d^2 - \delta^c b^2}{2r \delta^c \delta^w (r+b-d+s)^2}$	$\frac{-(d-b)^2 (\delta^c + \delta^w)}{2r \delta^c \delta^w (r+b-d+s)^2}$	$\frac{-b^2 \delta^w - d^2 \delta^c + 2bd(\delta^c + \delta^w)}{2r \delta^c \delta^w (r+b-d+s)^2}$

Closed-form solutions for all variables

I'll emphasize a graphical exposition

Preuve évidente du réchauffement de la planète

