Technology Neutrality vs. Policy Discrimination: Optimizing Support for Competing Green Technologies

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May 25, 2025

Introduction

Context:

Competing Green Technologies: Hydrogen Supply and Demand

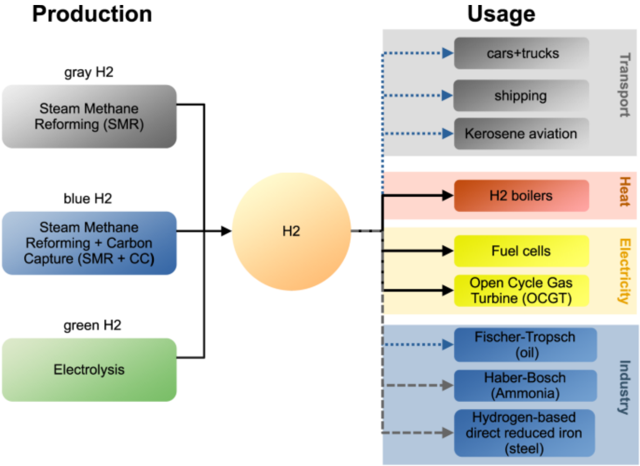


Figure: *Hydrogen Production and Demand (Zeyen 2022)*

Motivation: Should Climate Policy be Technology-Neutral?

- **Context:** Many low-carbon technologies remain costly, immature, and face high uncertainty.
  - Particularly true in hard-to-abate sectors (e.g. industry, transport).
  - Multiple competing options may serve similar decarbonization goals.
- **Focus on Carbon Contract for Differences:** Forward carbon price to support clean investments, with different goals:
  - Correcting for a too-low expected EU ETS price
  - Derisking revenue streams exposed to carbon price volatility.
  - Supporting investment in less mature technologies whose risk profile translates into high capital costs.
- **Core question:** Should support remain *technology-neutral* or be *technology-specific*?
  - Cost structures and financing risks vary across technologies.
  - Uniform support may misallocate resources toward less risky options.
  - But targeting risks misjudging future competitiveness.
- **Our approach:**
  - Compare policy instruments under asymmetric information and cost heterogeneity.
  - Apply to green vs. blue hydrogen competition under CCfDs.
  - Study trade-offs between instruments (quantity vs. price) and targeting (neutral vs. specific).

Related Literature

- **Prices vs. Quantities under Uncertainty:** Weitzman (1974) and extensions
  - Trade-offs under asymmetric information and imperfect substitutability (Williams III 2002; Meunier 2011; Weitzman 2020)
  - Our contribution: two competing abatement technologies + technology-specific cost wedges
- **Technology-neutral vs. technology-specific policies:**
  - Fabra and Montero (2023): discrimination justified by the cost of public funds
  - Our approach: support justified by financing barriers or externalities
- **Risk aversion and CCfDs:**
  - CCfDs lower investment risks and financing costs (Richstein 2017; Richstein and Neuhoff 2022; Jeddi et al. 2021)
  - Role of revenue certainty vs. investment barriers (Chiappinelli and Neuhoff 2020; Chaton and Metta-Versmessen 2023)
- **Financing constraints for green technologies:**
  - Clean tech access to capital and maturity gaps (Hall and Lerner 2010; Polzin et al. 2021; Ang et al. 2017; Brunnschweiler 2010)
  - Few papers model technology-specific support explicitly

Objectives and preview of the results

Main research questions

- **Normative question:** *Should climate policy be technology-neutral or targeted?*
- **Application:** *What is the optimal design of CCfDs for green vs. blue hydrogen in Europe?*
- **Methodology:** *A partial equilibrium model with competing technologies under asymmetric information and risk premia*

Main findings

- Technology-neutral policies distort allocation when technologies face heterogeneous financing risks.
- Targeted subsidies (e.g. differentiated CCfDs) improve welfare by correcting these distortions.
- The gains from targeting are higher when technologies are close substitutes (strong competition).
- Combining a neutral quota with technology-specific subsidies outperforms specific and neutral quotas.
- In a calibrated model for green vs. blue H_2, targeted support nearly doubles the share of blue hydrogen.

Main Model

Model Set-up: Two Competing Abatement Technologies

- **Technologies:** Two abatement options $i \in \{1, 2\}$ with long-term capacities q_i, total abatement $q = q_1 + q_2$
- **Regulator's perspective (social planner):**
  - **Social cost function:**

$$C(q_1, q_2) = (c_1 + \theta_1)q_1 + (c_2 + \theta_2)q_2 + \frac{\beta_1}{2}q_1^2 + \frac{\beta_2}{2}q_2^2 + \gamma q_1 q_2$$

    θ_i: cost shocks (mean zero); γ: substitutability between technologies
  - **Public benefit of abatement:**

$$B(q) = \left(a - \frac{b}{2}q\right)q$$

  - **Social welfare:**

$$W(q_1, q_2, \theta_1, \theta_2) = B(q_1 + q_2) - C(q_1, q_2)$$

- **Firm's perspective:**
  - **Perceived private cost:**

$$\tilde{C}(q_1, q_2) = (c_1 + \rho_1 + \theta_1)q_1 + (c_2 + \rho_2 + \theta_2)q_2 + \frac{\beta_1}{2}q_1^2 + \frac{\beta_2}{2}q_2^2 + \gamma q_1 q_2$$

    ρ_i: cost premiums reflecting risk aversion
  - **Profit maximization under prices (p_1, p_2):**

$$\Pi = p_1 q_1 + p_2 q_2 - \tilde{C}(q_1, q_2)$$

Model Set-up: Instruments and Timing

- **Objective:** compare four realistic policy instruments:
  - **Price-based:** one price p (neutral), or two prices p_1, p_2 (specific)
  - **Quantity-based:** one quota Q (neutral), or two quotas Q_1, Q_2 (specific)
- **Timing:**
  - **Stage 1:** regulator sets instrument level before knowing cost shocks θ_i
  - **Stage 2:** firms observe θ_i, choose q_i accordingly
- **Welfare notation:**

$$W_P^N, W_P^S, W_Q^N, W_Q^S$$

where P = price, Q = quota; N = neutral, S = specific
The expected values of quantities are denoted $\bar{q}_i$.
The optimal allocation q_1^*, q_2^* is the allocation that maximizes the social Welfare.

Quotas: Technology-neutral vs. Technology-specific

- **Technology-specific quotas** Q_1, Q_2:
  - Quantities fixed ex ante; unaffected by θ_i
  - Optimal quotas: $Q_i^* = \bar{q}_i^*$ (based on socially optimal allocation)
  - Cost premiums ρ_i do not influence optimal allocation
- **Technology-neutral quota** $Q = Q_1^* + Q_2^*$:
  - Market-clearing price $\bar{p}$ ensures $q_1 + q_2 = Q$
  - Allocation distorted by risk premiums and shocks:

$$q_1 = Q_1^* - \frac{\rho_1 - \rho_2}{\beta_1 + \beta_2 - 2\gamma} - \frac{\theta_1 - \theta_2}{\beta_1 + \beta_2 - 2\gamma}$$

Proposition 1 – Welfare Difference

$$W_Q^N - W_Q^S = \frac{1}{2} \cdot \frac{\mathbb{E}[(\theta_1 - \theta_2)^2] - (\rho_1 - \rho_2)^2}{\beta_1 + \beta_2 - 2\gamma}$$

- A single quota allows quantities to adjust to cost shocks ⇒ gains from flexibility.
- But it fails to correct cost premiums ⇒ distorted allocation across technologies.
- These two effects work in opposite directions in the welfare comparison.

Technology-Neutral Quota with Two Subsidies

- Adding technology-specific subsidies to a single quota restores efficient allocation while preserving the adaptation to random cost shocks.

Proposition 2

A technology-neutral quota together with two subsidies ρ_1 and ρ_2 for quantities produced with technologies 1 and 2 outperforms two technology-specific quotas by:

$$\frac{1}{2} \frac{\mathbb{E}[(\theta_1 - \theta_2)^2]}{\beta_1 + \beta_2 - 2\gamma}$$

The gain from adding subsidies increases with γ, and equals:

$$\frac{1}{2} \frac{(\rho_1 - \rho_2)^2}{\beta_1 + \beta_2 - 2\gamma}$$

- Subsidies offset cost premium distortions without constraining total quantity.
- Higher substitutability (γ) magnifies both misallocation and the benefit of correcting it.

Prices : Technology-specific vs. Technology-neutral

- With price-based instruments, the regulator sets prices ex ante based on expected firm behavior.
- **Technology-specific prices** internalize risk premiums:

$$p_i^* = B'(\bar{q}^*) + \rho_i$$

- **Uniform price** averages across technologies, compounding distortions:

$$p^* = \frac{(\beta_2 - \gamma)p_1^* + (\beta_1 - \gamma)p_2^*}{\beta_1 + \beta_2 - 2\gamma}$$

Proposition 3 – Welfare Gain from Price Discrimination

$$W_P^S - W_P^N = \frac{1}{2} \cdot \frac{(\rho_2 - \rho_1)^2}{\beta_1 + \beta_2 - 2\gamma}$$

The gain increases with the substitutability parameter γ.

- Discrimination corrects misallocation due to heterogeneous risk.
- The gain from discriminating is the same as the gain obtained by introducing two subsidies into a single, technology-neutral auction

Neutral Price vs Quantity Instruments

- The distortion introduced by risk premiums plays no role here.
- **Three key factors shape the price versus quantity comparison:**
  - **Cost shocks** (θ_i): increases the value of flexibility.
  - **Slope of marginal benefit and cost**
  - **Substitutability** (γ): determines the degree of competition between technologies.

Proposition 4 – Neutral Price vs Neutral Quantity

$$W_P^N - W_Q^N = \frac{1}{2\Gamma^2} \cdot (\Gamma - b) \cdot \mathbb{E}\left[\left(\frac{(\beta_2 - \gamma)\theta_1 + (\beta_1 - \gamma)\theta_2}{\beta_1 + \beta_2 - 2\gamma}\right)^2\right]$$

in which $\Gamma = \dfrac{\beta_1\beta_2 - \gamma^2}{\beta_1 + \beta_2 - 2\gamma}$

- Γ: slope of marginal cost. b: slope of marginal benefit.
- This reflects the classic **Weitzman (1974)** trade-off:
  - If $\Gamma > b$: **price-based instruments preferred**.
  - If $\Gamma < b$: **quantity-based instruments preferred**.
- Welfare difference is proportional to the **variance of the cost shock**.

Specific Price vs Quantity Instruments

Proposition 5 – Specific Price vs Specific Quantity

$$W_P^S - W_Q^S = \underbrace{\frac{1}{\Gamma}\,\mathbb{E}\left[\left(\frac{(\beta_2-\gamma)\,\theta_1 + (\beta_1-\gamma)\,\theta_2}{\beta_1+\beta_2-2\gamma}\right)^2\right]}_{\text{Aggregate shock}} + \underbrace{\frac{\mathbb{E}[(\theta_1-\theta_2)^2]}{\beta_1+\beta_2-2\gamma}}_{\text{Reallocation}} - \underbrace{\frac{b}{2\Delta^2}\,\mathbb{E}\left[((\beta_2-\gamma)\,\theta_1+\ldots)^2\right]}_{\text{Weitzman}}$$

- The comparison can be decomposed into three interpretable effects:
  - Weitzman trade-off (see proposition 4)
  - **Agregate shock effect:** captures the effect of the aggregate shock on the total quantity.
  - **Reallocation effect:** captures the gain for price instrument from reallocation between technologies, and depends on the dispersion of the individual shocks.
- **Role of γ:**
  - Higher γ leads to stronger reallocation gains for prices (technologies compete more).
  - But also increases aggregate volatility → ambiguous effect.

Application to CCfDs

Technology-neutral or specific support?

- **Purpose of CCfDs:** reduce investment risk by guaranteeing a CO_2 price $\Rightarrow$ lower capital costs for clean tech developers (Richstein and Neuhoff 2022)
- **Hybrid nature of CCfDs:**
  - Theoretically price-based (guaranteed CO_2 price)
  - Practically quantity-driven (allocation via auctions, fixed decarbonization targets)
- **Firms are risk-averse:** risk-adjusted cost includes a premium : $\rho_i = \lambda(\sigma^2 + \sigma_i^2)$ where σ^2 = carbon price risk, σ_i^2 = tech-specific cost risk, λ risk aversion.
- **Naive CCfD effects:** Removes σ^2, but leaves σ_i^2 untreated
- **Policy implication:**
  - Uniform CCfDs induce misallocation when $\rho_1 \neq \rho_2$
  - Optimal CCfD should adjusts for ρ_i
- **Welfare loss of naive CCfD:**

$$W_P^N - \hat{W} = \frac{\lambda^2}{2\Gamma + b}\left[\frac{(\beta_1 - \gamma)\sigma_2^2 + (\beta_2 - \gamma)\sigma_1^2}{\beta_1 + \beta_2 - 2\gamma}\right]^2$$

$\Rightarrow$ Loss grows with premium differences and competition intensity (γ)

Numerical application

Microfounded Model

Analytical exploration, without asymmetric information

- A continuum of polluting sites faces a choice:
  - Adopt technology 1 or 2 (e.g., green or blue H_2)
  - Or remain inactive (if both net gains are negative)
- Sites differ by **cost pairs** (c_1, c_2) drawn from joint distribution $f(c_1, c_2)$
- With technology-specific prices p_1, p_2 and cost premiums ρ_1, ρ_2:
  - Tech 1 chosen if $p_1 - (c_1 + \rho_1)$ dominates
  - Tech 2 chosen if $p_2 - (c_2 + \rho_2)$ dominates
- Resulting total welfare (without asymmetric information):

$$W = B(q_1 + q_2) - \int_{\mathcal{D}_1} c_1 f(c_1, c_2) dc_1 dc_2 - \int_{\mathcal{D}_2} c_2 f(c_1, c_2) dc_1 dc_2. \quad (1)$$

- The intensity of competition depends on how many firms are nearly indifferent — i.e., when $c_1 \approx c_2$.
- The more firms are close to this frontier, the more responsive the technology mix is to small price changes (i.e $\frac{\partial q_1}{\partial p_2}$). This responsiveness plays the same role as γ in the quadratic model.
  $\Rightarrow$ A high γ corresponds to a dense indifference frontier in the microfounded model.

Illustration: Misallocation from Ignoring Cost Premiums

Optimal vs. biased allocation across sites

- **Left:** Optimal allocation with decentralized prices $p_i = B'(q^*) + \rho_i$
- **Right:** Biased equilibrium under uniform price without correcting for cost premiums
- Two distortions:
  - Sites that should adopt remain inactive (gray area)
  - Sites adopt the wrong technology (hatched area)

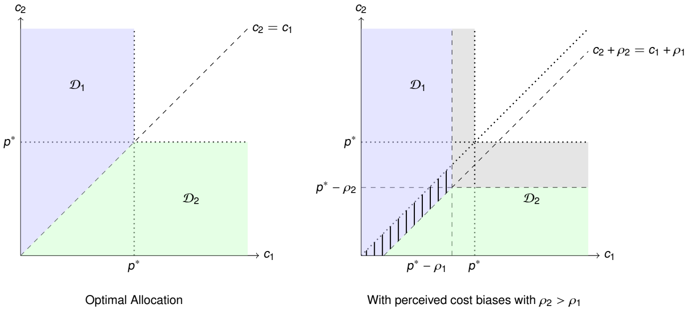


Figure: Distribution of abatement across sites at the optimum and biased equilibrium

Calibration

From grey to low-carbon hydrogen in Europe

- **Reference:** Grey hydrogen via SMR without CO_2 capture.
- **Clean alternatives:**
  - **Technology 1 – Green H_2:** electrolysis with renewable electricity
  - **Technology 2 – Blue H_2:** SMR + CCS (high-capture variant, 95%)
- **Data:** 9.2 Mt/year of grey hydrogen production in Europe
- **Decarbonization Target:** 55% reduction target for industrial emissions by 2030

Parameter	Meaning	Value	Source
b_1, b_2	Energy use (green / blue H_2)	0.05 / 0.04 MWh/kg	IEA
c_1, c_2	Fixed costs (€/kg)	1.75 / 1.9	EU H_2 Observatory
θ_1, θ_2	Cost shocks (€/kg)	$\mathcal{N}(0, 1.1^2)$ / $\mathcal{N}(0, 1.3^2)$	Internal calibration
λ	Risk aversion	5	Epstein et al.
$\sigma_{K,1}$ / $\sigma_{K,2}$	CAPEX uncertainty (€/kg)	0.14 / 0.38	OECD
σ_{pCO_2}	Carbon price volatility (€/kg)	0.29	EEA
Q^*	Decarbonization target	5.1 Mt H_2/year	EU H_2 Observatory
(a, b)	Abatement benefit parameters	$(8.6, 10^{-6})$	Internal

Distribution of Energy Input Costs

Heatmap of hydrogen production by site-level energy prices

- Sites are positioned by their energy input costs:
  - x-axis: Estimated Levelized Cost of Electricity (LCOE) in 2030, impacting the cost of green H_2
  - y-axis: Estimated natural gas price, impacting the cost of blue H_2
- Each cell represents a grey H_2 production unit in 2030
- This cost landscape shapes spatial heterogeneity in our model

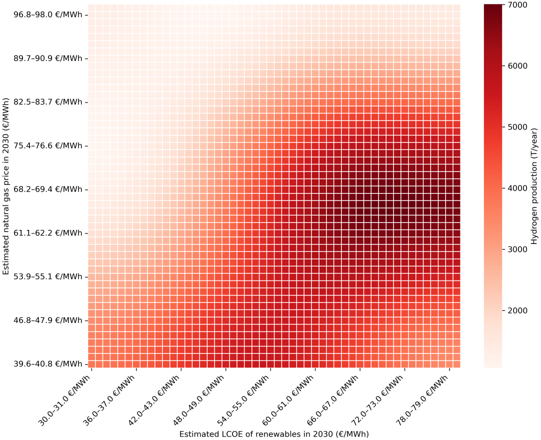


Figure: Grey H_2 production density by projected energy costs (2030)

Main Results

Overview of policy outcomes

Scenario	Welfare (bn)	Price (/tCO_2)	Green H_2 (%)	Blue H_2 (%)
0. CCfD naive	8.13	580	21.4	9.2
1. Price-based, techno-neutral	12.12	690	45.3	14.3
2. Price-based, techno-specific	13.24	(640, 770)	30.2	33.4
3. Quota-based, techno-neutral	12.04	680	40.2	16.1
4. Quota-based, techno-specific	13.04	(600, 770)	21.2	34.8
5. Quota-based, neutral, subsidies	13.19	(630, 750)	29.1	29.0

Table: Expected outcomes under alternative policy designs

- **Naive CCfD** underperforms: too little abatement, overly green mix.
- **Targeting matters:** tech-specific instruments significantly improve welfare and balance the mix.
- **Best outcome:** tech-specific prices (Scenario 2).
- **Neutral quota + subsidies** (Scenario 5) nearly as good.
- **Targeting gains** greater than **instrument choice gains**.

Sensitivity Analysis: Spatial Distribution of Sites

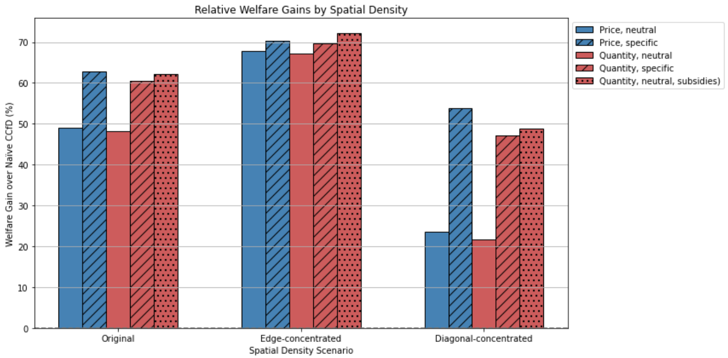


Figure: Welfare gains vs. naïve CCfD across spatial scenarios

- Higher site concentration along the diagonal $\Rightarrow$ higher substitutability (high γ) $\Rightarrow$ larger benefit from technology-specific policies
- Edge-concentrated configuration $\Rightarrow$ lower γ $\Rightarrow$ technology-neutral instruments perform relatively better

Sensitivity Analysis: Decarbonization Target

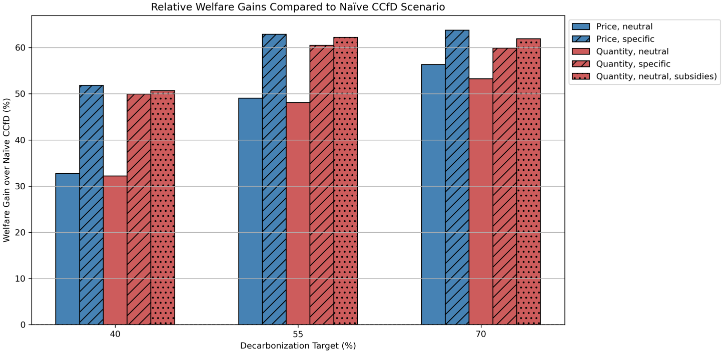


Figure: Welfare gains vs. naïve CCfD at 40%, 55%, and 70% decarbonization targets

- Higher targets ⇒ more costly to under-decarbonize ⇒ quota-based instruments gain relative importance
- At low ambition levels, technology-specific instruments bring clearer benefits, especially for quantity-based policies

Sensitivity Analysis: Risk Aversion

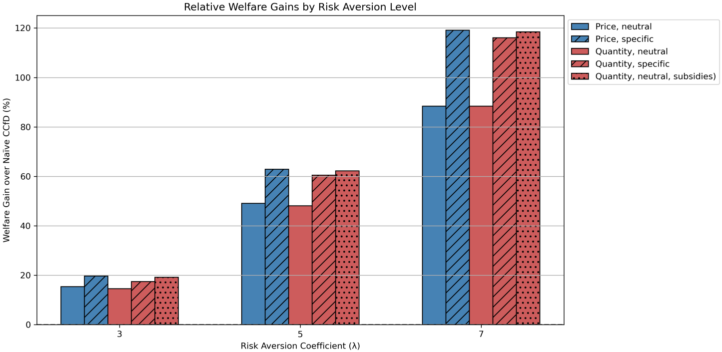


Figure: Welfare gains vs. naïve CCfD for different values of risk aversion λ

- Higher $\lambda \Rightarrow$ stronger cost premium distortions $\Rightarrow$ greater gains from technology-specific support
- At high risk aversion, quantity-specific instruments close the gap with price instruments

Sensitivity Analysis: Cost of Missing Target

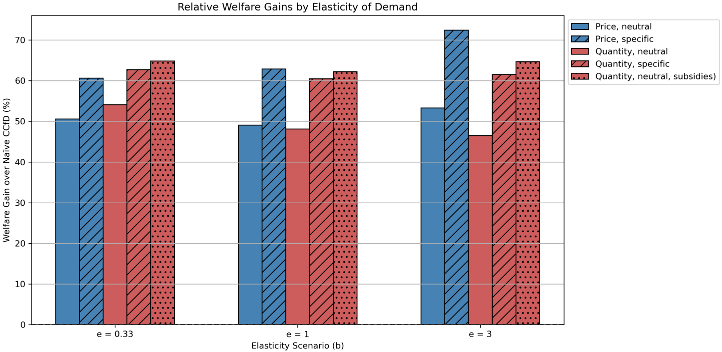


Figure: Welfare gains vs. naïve CCfD for different values of penalty parameter e

- Low e (high penalty b) $\Rightarrow$ quantity-based instruments preferred: they guarantee the target is met
- High e (low penalty) $\Rightarrow$ price-based instruments regain advantage; targeting remains robust in both cases

Conclusion

Conclusion

Main insights

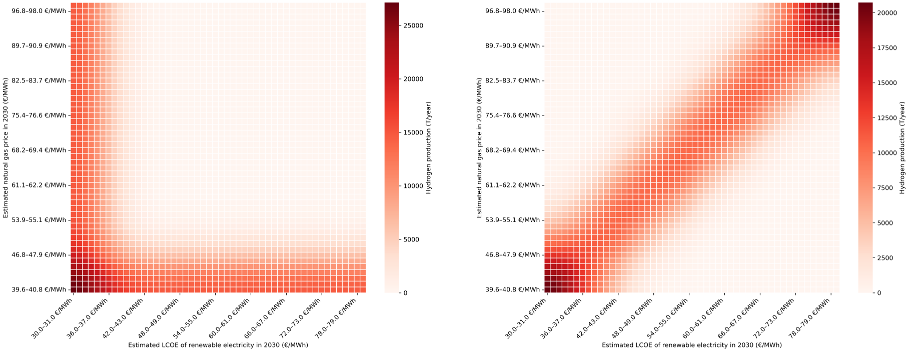
- **Policy design under uncertainty:** Our model shows how asymmetric information and heterogeneous risk premiums distort technology allocation.
- **Key theoretical results:**
  - With quantities, neutral quotas + targeted subsidies outperform all other designs.
  - With prices, technology-specific instruments always dominate uniform ones.
  - The choice between price vs. quantity depends on sensitivity to cost shocks.
- **Numerical illustration:** Applied to green vs. blue hydrogen competition in Europe. Confirms: *Targeting is most valuable when technologies are close substitutes.*

Limitations and future directions

- Risk premiums assumed observable — learning or monitoring could be modeled.
- Full substitutability in emissions is a strong assumption (esp. for blue H_2).
- Uncertainty on true abatement potential (e.g., methane leakage) should be internalized.

Appendix

Appendix



(a) Edge-concentrated scenario **(b)** Diagonal-concentrated scenario

Figure: Smoothed hydrogen production by projected energy costs in 2030 under two alternative spatial distributions of sites. Production values are diffused using a Gaussian filter.