DIW BERLIN

Stores Abschlußworkshop

Strategic behaviour and market power in the investment and operation decisions of a hydro pump-storage plant

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Quantitative Analysen im Projekt StoRES: Übersicht

	Speicher-typen	Zeitho-rizont	Speicheranwendungen						
			Tagesaus-gleich	Saison-ausgleich	Überschuss-integration	Lastgra-dienten	Spitzen-last	Netzent-lastung	Regel-leistung
Überschüsse (*Energy Policy 2014*)	Li-Ion (2h) PSW (8h) P2G (500h)	2022 2032 2050	✓	✓	✓				
Interaktionen Übertragungs-netz *(EEEP 2014)*	PSW (5-8h)	2012 2024 2034	✓		✓		(✓)	✓	
Vergleich von Stromspeichern *(DIW DP in Arbeit)*	Diverse Stromsp. (2-200h) DSM	2010 2020 2030	✓		✓	✓			✓ (in Arbeit)
Langfristiger Speicherbedarf *(IAEE 2014, DIW DP in Arbeit)*	Li-Ion PSW P2G (E/P end.)	Green-field, EE-Anteile 0-100%	✓	✓	✓	(✓)	✓		✓
Marktmacht *(DIW DP in Arbeit)*	PSW / Reservoirs	Stilisiert	✓		(✓)				

Agenda

1. Is strategic behaviour of storage an issue? Practice vs. theory
2. The challenges of numerical modelling
3. Preliminary results
4. Conclusions and outlook

1

Is strategic behaviour of storage an issue? Practice vs. theory

1 Is strategic behaviour of storage a non-issue?

Detecting market power in hydro reservoir systems is tricky; theoretical insights have limited applicability

- Market power of hydro reservoir may be difficult to identify

⇒ "Water value" is difficult to quantify independently

⇒ A lot of research on New Zealand (e.g., Philpott and Guan, 2013)

⇒ In European context: is it efficient to invest in "green batteries" for German renewable generation in Norway or the Alps?

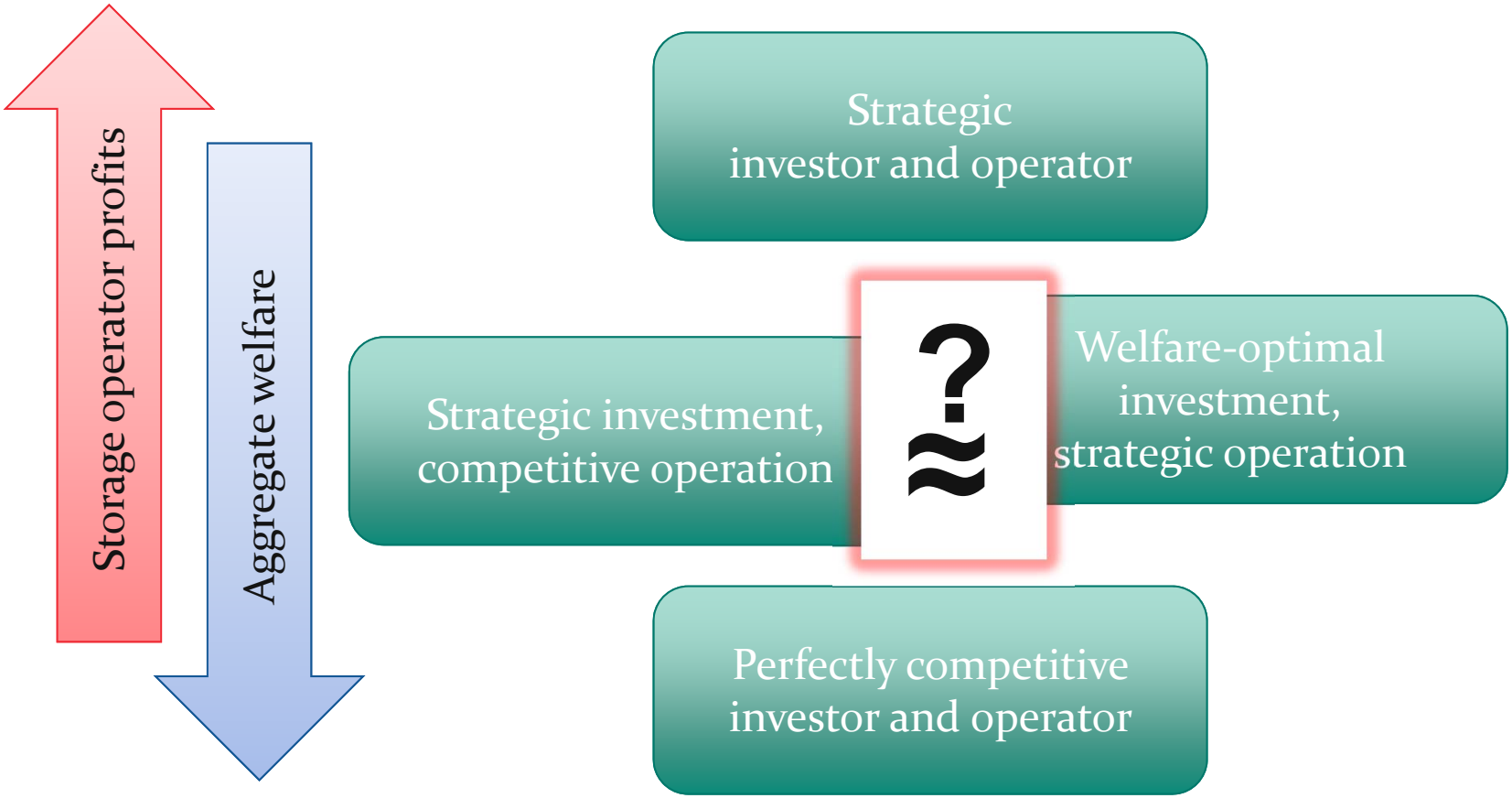
- In a stylized theoretical model, there is no difference between strategic behaviour in investment or operation

  See Kreps & Scheinkman (1983)

⇒ But this may not be true in more complicated market settings

1 Strategic behaviour in investment and operation

We analyse whether the regulatory focus should be put on investment or operation of hydro pump-storage



1 The characteristics of pump-hydro storage

We aim to investigate the investment decision regarding technical characteristics depending on the market power case

There are multiple technical decisions regarding the investment into hydro pump-storage plants

- Injection capacity
- Extraction capacity
- Storage reservoir size

⇒ Does a strategic investor choose different designs and scale of the reservoir and turbines than a welfare-optimizing planner?

2

The challenges of numerical modelling and the curse of dimensionality

2 How to model strategic behaviour in market equilibrium models?

Cournot models are of limited use in this context; we require a Stackelberg model to capture strategic behaviour

- The “standard approach” is the use of Cournot market power (or equivalently Supply Function Equilibria or Conjectural Variations)

⇒ But models in this class usually assume that strategic players are unaware of the actual reaction of their rivals

- Properly capturing the market power exertion contingent on actual capacity constraints of rivals requires a Stackelberg game structure

⇒ Mathematically, this can be formulated as a two-stage model (Mathematical Program under Equilibrium Constraints, MPEC)

2 The mathematical formulation - Introduction

Two-stage equilibrium models can be used to formulate and solve Stackelberg leader-follower games

- The problem formulation:

max Profits of Stackelberg leader

s.t. Market equilibrium of followers

- The mathematical notation:

⇒ Replace the "market equilibrium" by first-order optimality (Karush-Kuhn-Tucker, KKT) conditions

$$\max_{x,y} \quad f(x,y)$$

$$\text{s.t.} \quad 0 \le g(x,y) \perp y \ge 0$$

2 The mathematical formulation – Current solution approaches

Solving an optimization subject to equilibrium constraints is mathematically challenging due to complementarity

- The complementarity conditions of the lower-level constraints make the numerical solution of such problems difficult

$$\max_{x,y} \quad f(x,y)$$

$$\text{s.t.} \quad 0 \le g(x,y) \perp y \ge 0$$

- There are several "standard" reformulations:
  - Disjunctive constraints (Fortuny-Amat and McCarl, 1981)
  - Reformulation using Schur's decomposition and SOS1 variables (Siddiqui and Gabriel, 2013)
  - Strong duality (Ruiz, Conejo and Smeers, 2012)

⇒ All approaches suffer from a curse of dimensionality!

2 The mathematical formulation – Some tweaks to make it work

We propose a reformulation to improve numerical efficiency replacing income and payments by rents

- The straightforward approach to model storage operator profit:

$$\max_{x,y} \quad \sum_{t \in T} p_t \vec{s}_t - p\bar{s}_t$$

$$\text{s.t.} \quad 0 = d_t + \bar{s}_t - g_t - \vec{s}_t \;,\; p_t \quad (\text{free})$$

- Instead, focus on the rents!

⇒ Assume that storage operation is controlled by a competitive player

⇒ But the strategic storage owner can restrict how much is used

$$\max_{x,y} \quad \sum_{t \in T} \vec{\mu}_t \vec{S}_t + \bar{\mu}_t \bar{S}_t$$

$$\text{s.t.} \quad 0 = d_t + \bar{s}_t - g_t - \vec{s}_t \;,\; p_t \quad (\text{free})$$

$$0 \le \vec{S}_t - \vec{s}_t \perp \vec{\mu}_t \ge 0$$

$$0 \le \bar{S}_t - \bar{s}_t \perp \bar{\mu}_t \ge 0$$

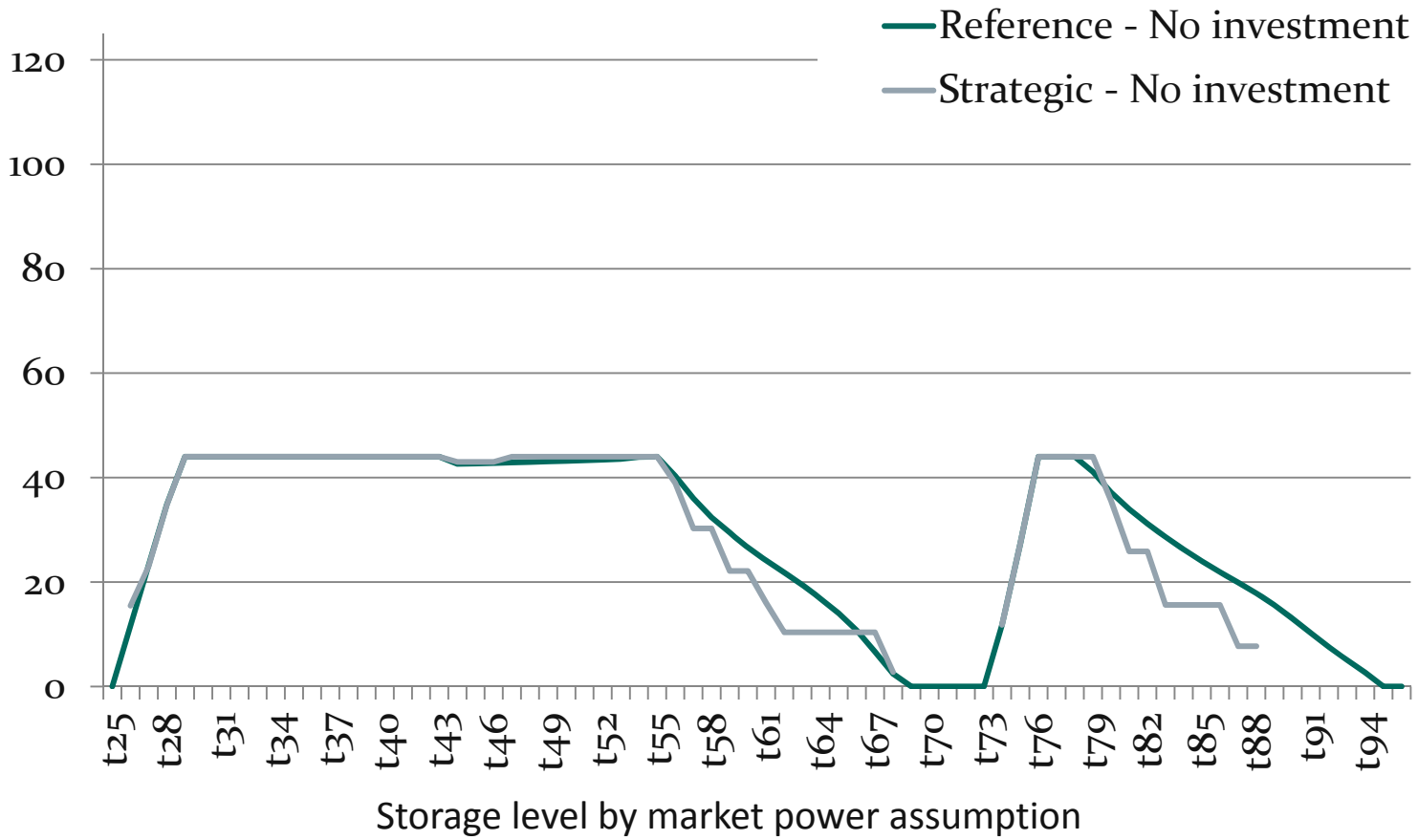
⇒ Additional benefit: Straightforward separation of operational vs. investment rents

3

Preliminary results

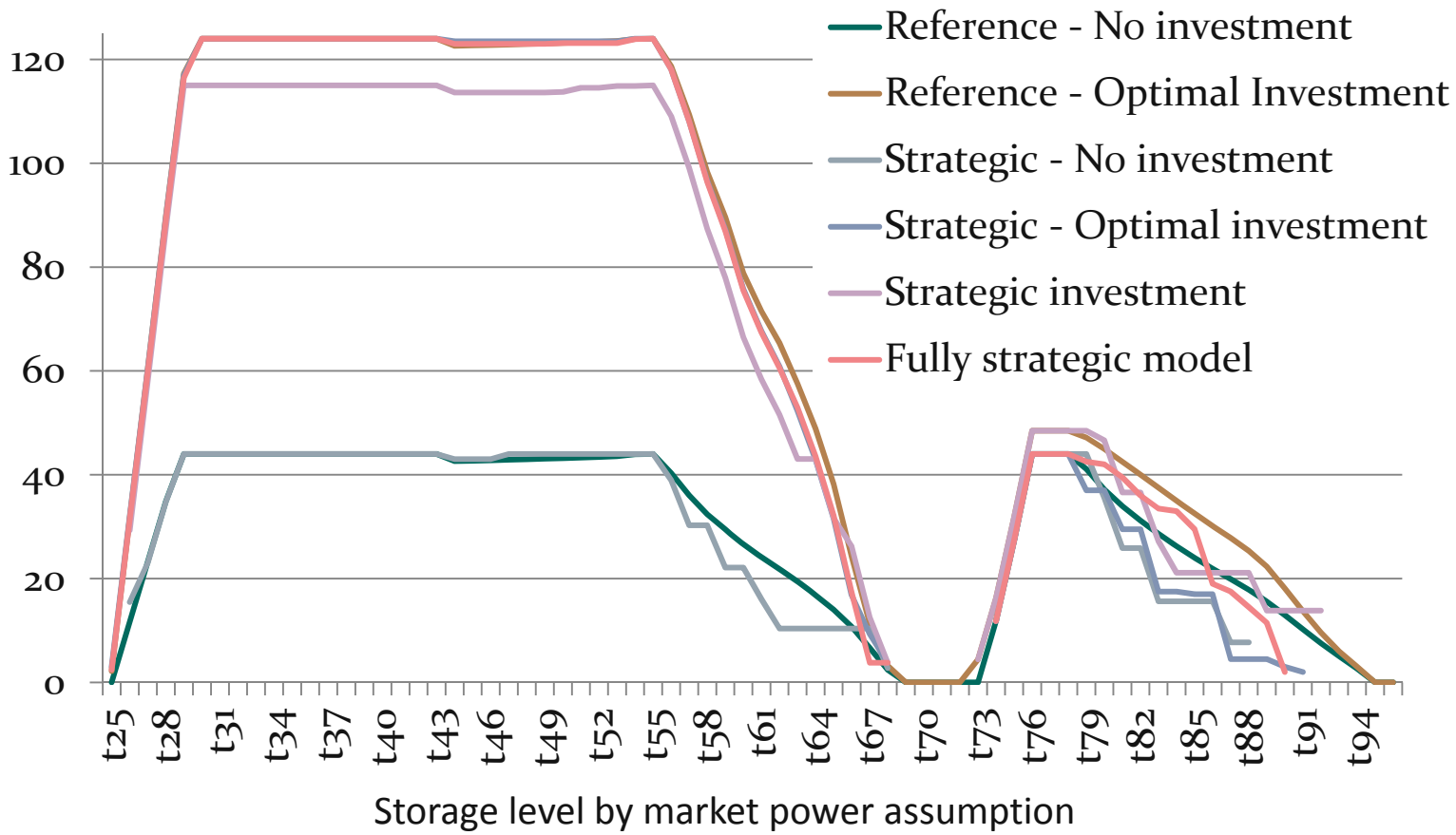
3 Preliminary results – Storage level based on a toy data set

Without any investment, a strategic pump-storage operator can earn additional rents by extracting more erratically



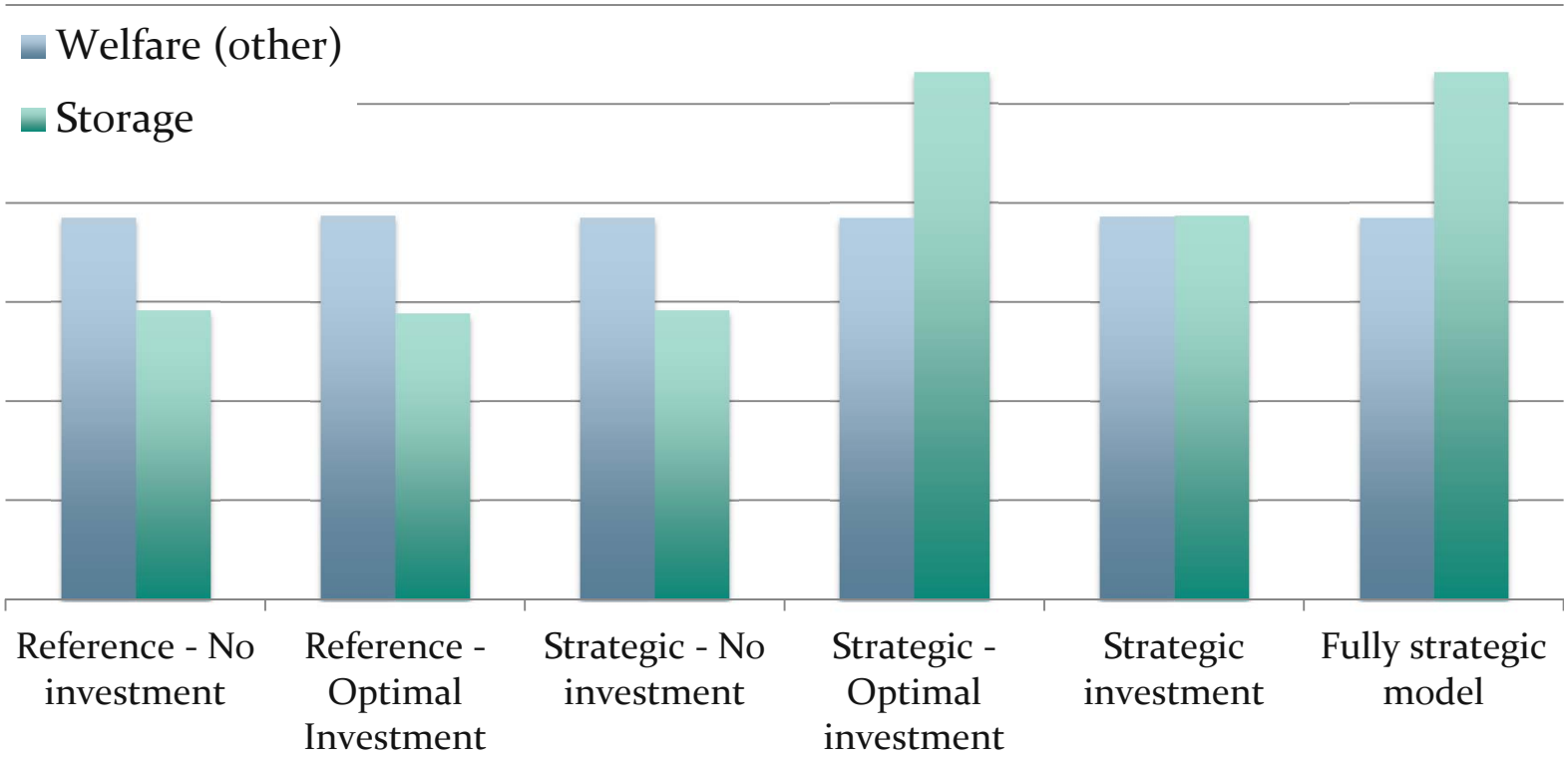
3 Preliminary results – Storage level based on a toy data set

When the storage plant owner is restricted to competitive operation, he invests less in reservoir capacity



3 Preliminary results – Welfare and profits

Strategic storage has a small impact on aggregate welfare, but the focus of regulation affects storage owner profits



Welfare for storage operators vs. others (consumers, generators) – indicative results only

4

Conclusions and outlook

4 Conclusion and outlook

We focus on the impact of strategic operation vs. investment of a hydro pump-storage plant

- Academic theory does not offer much insight whether a regulatory focus on strategic operation or investment should be a priority to mitigate market power exertion and welfare losses
- We propose a Stackelberg model reformulation to distinguish between the rents gained from strategic operation and investment

- Further research:

⇒ Alternative methods to improve computational efficiency

⇒ Uncertainty and rolling horizon optimization approach

⇒ Strategic bidding in balancing markets

Thank you very much for your attention!

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