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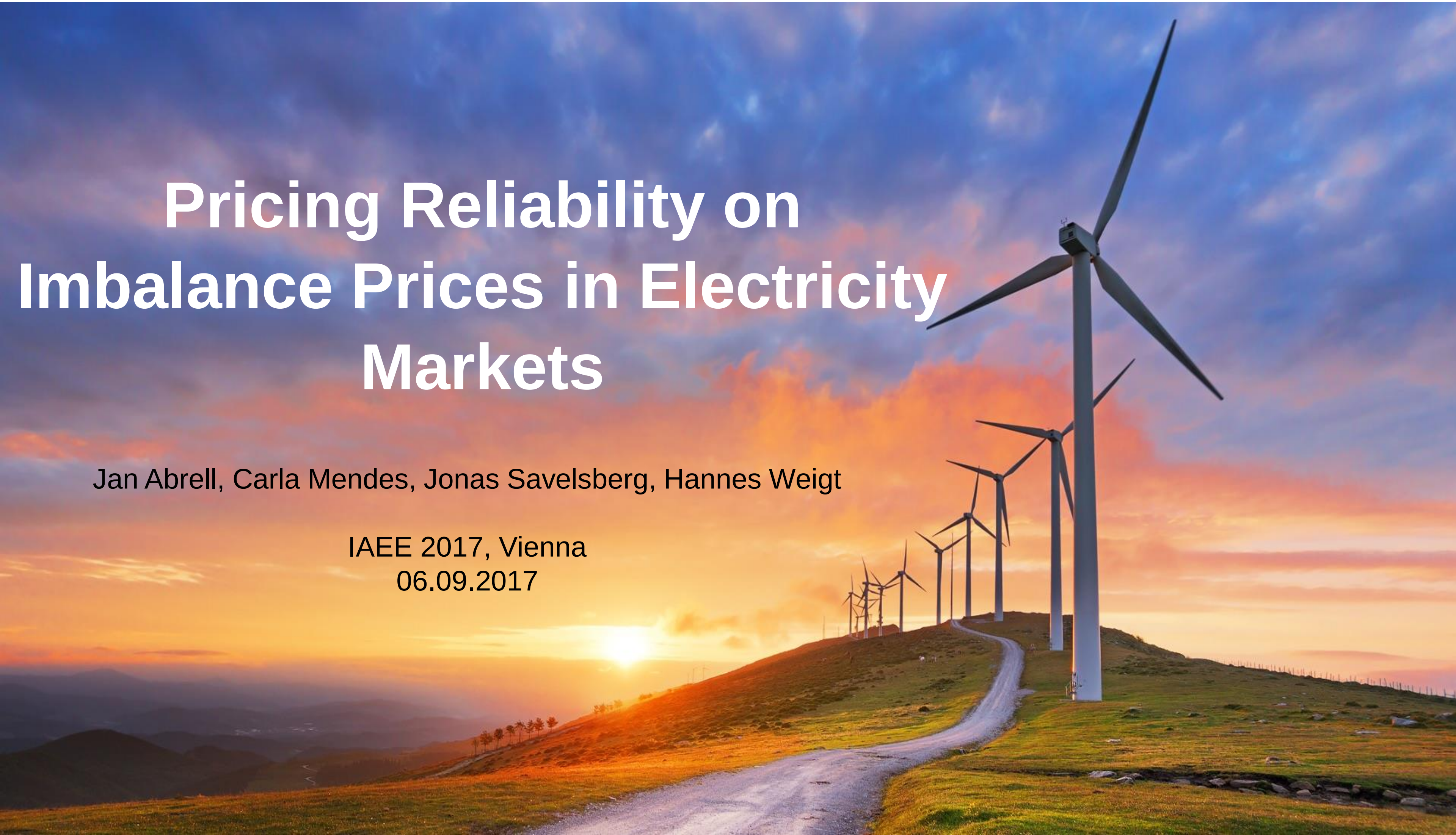

Pricing Reliability on Imbalance Prices in Electricity Markets

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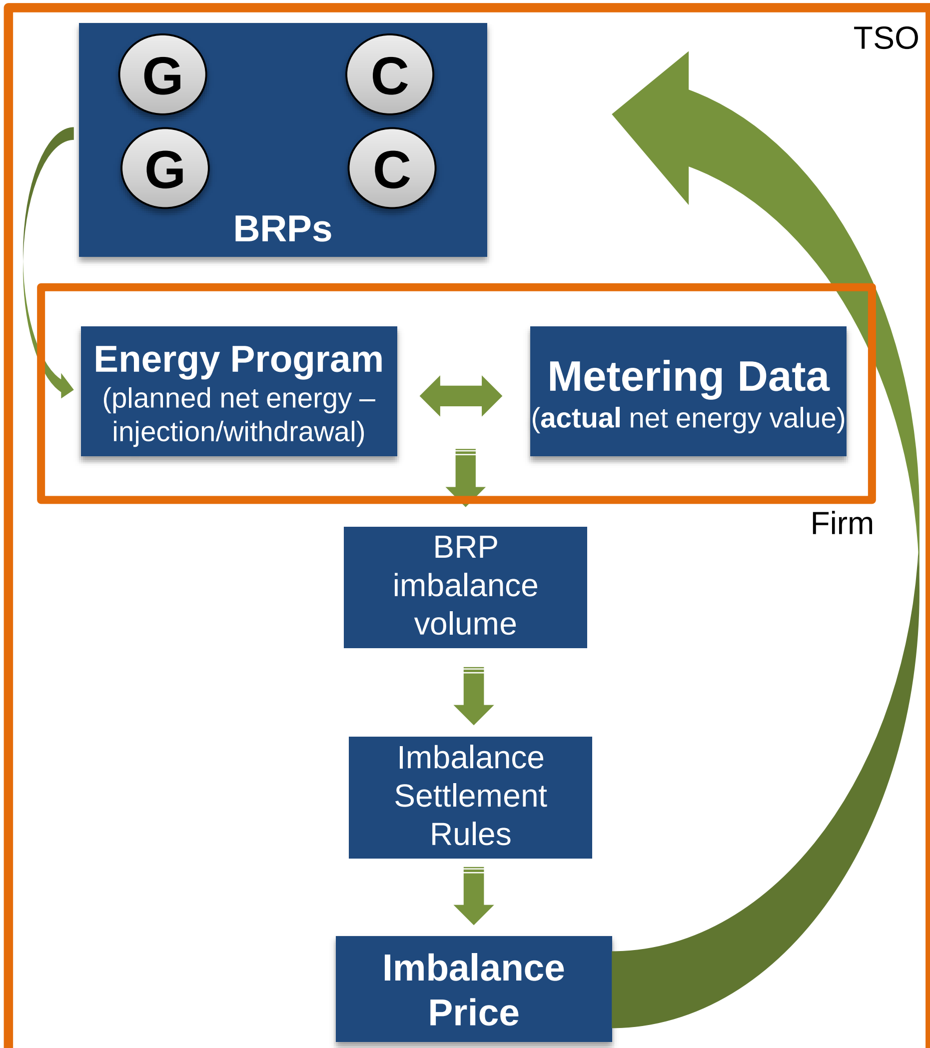
Outline

1. **Motivation**
2. **Imbalance Settlement Designs**
3. **Model Framework**
4. **Conclusion**

Motivation – Why do we need balancing?



System Imbalance **Short**: D>S

High price for activated upward regulation bids

Increase the effort to provide accurate energy programs

System Surplus / System Imbalance **Long**: D<S

Low price for activated downward regulation bids

Reduces the incentive to balance their portfolio

How to price caused systems imbalances?
Is the current system able to ensure that

Methodology

- **Imbalance Designs**
  - Review on Imbalance Settlements in Europe
- **Firm Behavior**
  - Bid strategy given imbalance prices
- **TSO Behavior**
  - How TSO respond to Firm's behavior setting the imbalance prices
- **Imbalance Rules**
  - Expand the models to include different imbalance rules
- **Numerical Simulation**
  - Numerical simulation applied to different countries

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Imbalance Settlement Designs in Europe

Country	Pricing based on	Mechanism	Symmetric/ asymmetric	Settlement time unit
Austria	Total costs	One-price	-	15 min.
Belgium	Marginal prices	Two-price	Symmetric	15 min.
Denmark	Marginal prices	Two-price (production) One-price (consumption)	Symmetric	15 min.
France	Marginal prices	Two-price	Symmetric	30 min.
Germany	Total costs	One-price	-	15 min.
Italy	Marginal prices	One-price (small BRP) Two-price (big BRP)	Symmetric	60 min.
Spain	Marginal prices	Two-price	Symmetric	60 min.
Switzerland	Marginal prices	Two-price	Asymmetric	15 min.
The Netherlands	Marginal prices	Two-price	Symmetric	15 min.

Papageorgiou, et al. (2016)

- **Different imbalance settlements lead to different market behaviours** and balancing market performances.
- Particular importance if governance, energy regulators and TSOs aim to integrate different balancing markets.

One-Price vs Two-Price System

One-Price System

		System Imbalance	
		Negative (Short)	**Positive (long)**
BRP Imbalance	**Negative (Short)**	$+MP_u$	$+MP_d$
	Positive (long)	$-MP_u$	$-MP_d$

MP_u = marginal price of upward regulation; MP_d = marginal price of downward regulation.

Two-Price System

		System Imbalance	
		Negative (Short)	**Positive (long)**
BRP Imbalance	**Negative (Short)**	$+AP_u * (1 + penalty_u)$	$+P_{DA}$
	Positive (long)	$-P_{DA}$	$-AP_d/(1 + penalty_d)$

AP_u = average price of upward regulation; AP_d = average price of downward regulation; P_{DA} = day-ahead power exchange price.

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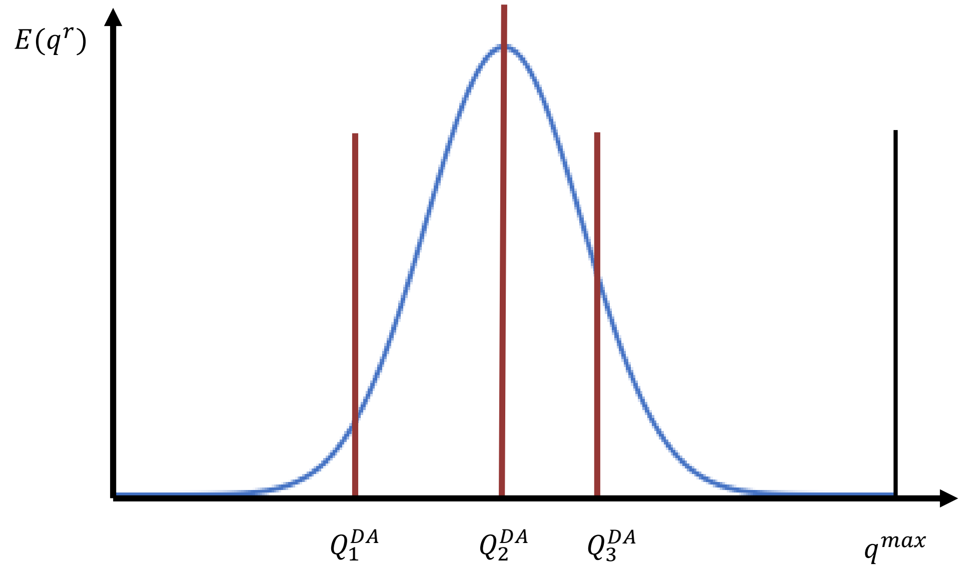
Assumptions

- Follow methodology presented in Zhan, et.al. (2012).
- Relation between SI and BRPI is not consider.
- RES producer with zero marginal costs.



- **Realization:** $q^r \sim \aleph^T(\bar{\mu}, \bar{\sigma}, 0, q^{max}; q^r)$

- **Imbalance Costs:**

$$I = \begin{cases} p^{IB-}(Q^{DA} - q^r), & Q^{DA} \geq q^r \\ p^{IB+}(q^r - Q^{DA}), & Q^{DA} < q^r \end{cases}$$

- **Prices:**
  - CASE 1: $0 \leq p^{IB+} \leq p^{DA} \leq p^{IB-}$
  - CASE 2: $p^{IB+} \leq 0 \leq p^{DA} \leq p^{IB-}$
  - CASE 3: $p^{IB-} \leq 0 \leq p^{DA} \leq p^{IB+}$

Two-Price System: RES Producer

$$\max_{Q^{DA}} \; p^{DA}Q^{DA} - p^{IB-}\int_0^{Q^{DA}} (Q^{DA} - q^r)\psi(q^r)dq^r + p^{IB+}\int_{Q^{DA}}^{q^{max}} (q^r - Q^{DA})\psi(q^r)dq^r$$

$$s.t.\, 0 \le Q^{DA} \le q^{max}$$

- **FOC**: $p^{IB-}\int_0^{Q^{DA}} \psi(q^r)dq^r + p^{IB+}\int_{Q^{DA}}^{q^{max}} \psi(q^r)dq^r + \lambda \ge p^{DA} \perp \quad Q^{DA} \ge 0$

  $q^{max} \ge Q^{DA} \perp \quad \lambda \ge 0$

Solutions		
$Q^{DA*} \quad \epsilon \quad [0, q^{max}] \quad , p^{IB+} = p^{DA} = p^{IB-}$		
$\mathbf{0 \le p^{IB+} \le p^{DA} \le p^{IB-}}$	$\mathbf{p^{IB+} \le 0 \le p^{DA} \le p^{IB-}}$	$\mathbf{p^{IB-} \le 0 \le p^{DA} \le p^{IB+}}$
$Q^{DA*} = \Psi^{-1}\left(\frac{p^{DA} - p^{IB+}}{p^{IB-} - p^{IB+}}\right), p^{IB+} < p^{DA} < p^{IB-}$	$Q^{DA*} = \Psi^{-1}\left(\frac{p^{DA} + p^{IB+}}{p^{IB-} + p^{IB+}}\right), -p^{IB+} < p^{DA} < p^{IB-}$	$Q^{DA*} = \Psi^{-1}\left(\frac{p^{IB+} - p^{DA}}{p^{IB-} + p^{IB+}}\right), -p^{IB-} < p^{DA} < p^{IB+}$

where, $\Psi^{-1}(\bar{\mu}, \bar{\sigma}, 0, q^{max}; p) = \Phi^{-1}(\bar{\mu}, \bar{\sigma}^2; \Phi(\bar{\mu}, \bar{\sigma}^2; 0) + p.(\Phi(\bar{\mu}, \bar{\sigma}^2; q^{max}) - \Phi(\bar{\mu}, \bar{\sigma}^2; 0)))$

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Two-Price System: RES Producer

	$0 \le p^{IB+} \le p^{DA} \le p^{IB-}$	$p^{IB+} \le 0 \le p^{DA} \le p^{IB-}$	$p^{IB-} \le 0 \le p^{DA} \le p^{IB+}$
p^{IB+}	1	-1	5
p^{DA}	3	3	3
p^{IB-}	5	5	-1
Q^{DA*}	**50**	**54**	**46**
p^{IB+}	4	-2	18
p^{DA}	10	10	10
p^{IB-}	18	18	-2
Q^{DA*}	**48**	**53**	**47**
p^{IB+}	1	-1,3	1,8
p^{DA}	1,5	1,5	1,5
p^{IB-}	1,8	1,8	-1,3
Q^{DA*}	**53**	**63**	**37**

- **Example:**
  - Capacity = 100 MW
  - Mean = 50
  - Std. Deviation = 10
- **Case 1:** results depend on the spread between imbalance prices and DA prices.
- **Case 2:** firms bid **more** energy in the DA market, increasing the probability of being **short** in the imbalance market.
- **Case 3:** firms bid **less** energy in the DA market, increasing the probability of being **long** in the imbalance market.

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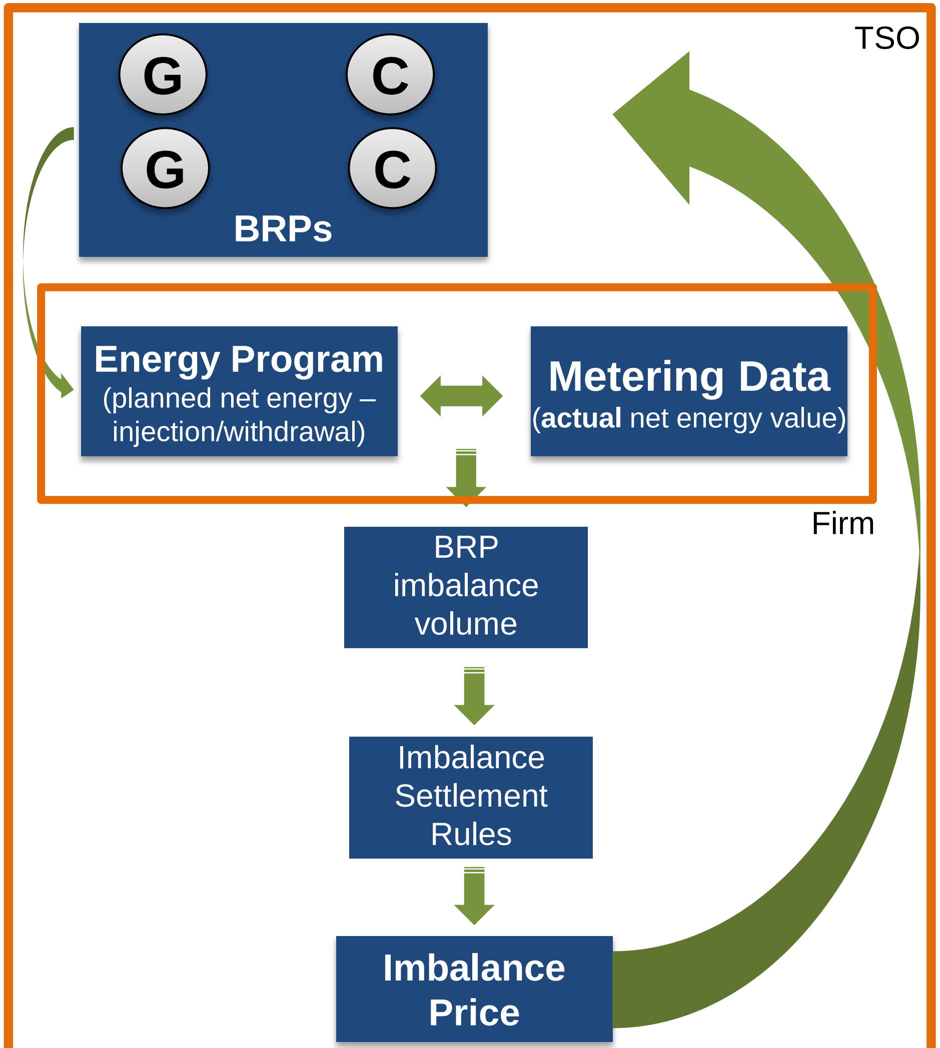
Model Framework: System Operator Problem



$$\min_{p^{IB-},p^{IB+}} E\left[C^{-}\left(Q^{DA}-q^{r}\right)|_{Q^{DA}\geq q^{r}}\right]+E\left[C^{+}\left(q^{r}-Q^{DA}\right)|_{Q^{DA}<q^{r}}\right]$$

$$s.t. \qquad E\left[p^{IB-}|_{Q^{DA}\geq q^{r}}\right]+E\left[p^{IB+}|_{Q^{DA}<q^{r}}\right]+\lambda \geq p^{DA}$$

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Conclusions

- Is there an incentive to deviate from our generation expectations, or specifically, from the generation expected value?

YES, there is!

- The optimal bid in the DA market depends on the relation between DA price imbalance prices, as well as, the properties of the probability distribution function.

- RES producer will bid in the market if the expected imbalance prices are sufficient high in relation to DA price to cover imbalance costs.

Next Steps

- Expand the model to the TSO Cost Minimization Problem.
- Refine the model to include system imbalance layer.
- Comparison between different countries regarding imbalance price settlements.

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