Which Specific Value of Demand-Response Mechanisms in Active Distribution Grids?

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Outline

- **Introduction**
- **Theoretical background and motivations**
- **The model**
- **Quantitative results and intuitions**
- **Conclusions and further developments**

Introduction

- Smart grids technologies will deeply modify distribution and final consumers' environment.
- Consumers' adaptation to signals:
  - *Information.*
  - *Prices.*
- Potentially, a new "era" in electricity markets as demand is usually seen as inelastic.
- In this context, Demand Response (DR) programs to be developed, but:
  - *Which level of available DR?*
  - *Which pricing schemes to value DR?*
  - *Which allocation between "actors" of the DR valorization?*

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Dynamic pricing and elasticity

- Lijensen (2007):
  - *Consumers of electricity are captive in the short run.*
- Haney & al. (2009), Faruqui & Sergici (2010):
  - *Demand could be elastic with SG and DR.*
- Herter (2007):
  - *Consumers could be worse off with DR mechanisms (dynamic pricing, critical peak pricing (CPP)).*
  - *Consumers' anticipate greater electricity bills with the use of DR tools (also Park et al., 2014).*
- Léautier (2014):
  - *Marginal value of Real Time Price (RTP) decreases with the number of consumers "covered".*

Examples of signals and load reductions

- Indirect feedback (education, information campaigns):
  - *Rather limited impact.*
  - *0 to 7% load reduction.*
- Direct feedback (in home display, monitoring data from smart meters):
  - *More significant.*
  - *2 to 15% load reduction.*
- Dynamic pricing (with or without direct load control):
  - *Highest leverage.*
  - *Up to 50% load reduction for some periods.*
  - *Consumers give lower value to direct load control.*

Acceptability of consumers for smart technologies

- To accept a technology, consumers must “value it” (Kaufmann et al., 2013).
- Their *Willingness To Pay* for smart meters and devices is positive (Pepermans, 2014):
  - *WTP of 200€ to change for a smart meter.*
  - *WTP for smart devices :*
    - *That do not impact privacy : 160€ - 185€.*
    - *That maintain their level of comfort : 110€ - 125€.*
    - *That are not « visible » : 80€ - 90€.*
- Thus, consumers value smart technologies and smart devices depending on their “footprint” at home.

Changes in behaviors and counter-incentives

- So, consumers could adapt their behavior when they are informed:
  - *Literature on dynamic pricing;*
  - *Smart meters and In Home Display create incentives (11% of load reduction);*
- But they want to preserve their comfort and privacy and have to be compensated for their adaptation.
- Moreover, some counter-incentives exist and could impact WTP and smart technologies benefits :
  - *Energy savings are lower than expected.*
  - *Some consumers need more information and more interactions with their suppliers.*
  - *Consumers sometimes believe that smart meters and smart devices only serve the interest of suppliers.*

The pricing of DR

- Crampes and Léautier (2010, 2015):
  - *Consumers must pay for the baseline of their consumption.*
  - *DR must be paid at market price.*
  - *Transfers towards producers could be efficient.*
- Chao (2011):
  - *Market price.*
  - *Second best pricing : difference between market price and retail rate.*
  - *Buying the baseline at market price.*
- Chao’s (2011) main results:
  - *Buying the baseline is the most efficient to improve the welfare.*
  - *Second best pricing then follows.*

Objectives and main results

- Objectives:
  - *Study DR programs under different pricing schemes using data of EPEX France.*
- Approach:
  - *Computing model with EPEX market data to simulate actors' revenues.*
  - *Relationships between actors are those of Chao (2011).*
- Preliminary results:
  - *Demand response reductions are greater when DR is paid at market price.*
  - *To reduce peak demand, buying the baseline or second best pricing have the same impact; only allocations of revenues differ.*
  - *DR could be profitable for welfare but costs should be reduced.*

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Main assumptions

- Four categories of actors :
  - *Generators, suppliers, DR providers, consumers.*
  - *Generators, consumers (or DRP) deal with the risk of DR.*
- DR could be valued on different markets, according to gate closure and probability to be used.
- Consumers buy electricity at the retail rate (RR) whereas Suppliers buy it at spot prices (p_s).
- DR providers:
  - *Sell the DR quantities on the market and they are remunerated at DR price.*
  - *Allocate part of this revenue to generators (α_k) and consumers (β_i).*
- 10 levels of DR (DR1→DR10):
  - *As in the literature, from 0-10% of total and 0-40% of rush demand.*

Three schemes of DR pricing (1/2)

- **Case 1 : LMP**
  - *« Market price » (LMP)*
  - *DR is valued at spot price (p_s)*
  - $p_{eff} = p_s$ *(with $p_s > 0$)*
- **Case 2 : SBP**
  - *« Second best price » (SBP)*
  - *DR remuneration is the difference between spot price and retail rate*
  - $p_{eff} = p_s - RR$ *(with $p_s > RR$)*
- **Case 3 : BB**
  - *« Buying the baseline » (BB)*
  - *Consumers buy their consumption baseline at RR*
  - $p_{eff} = p_s$ *(with $p_s > RR$)*

Three schemes of DR pricing (2/2)

- In **case 1 (LMP),** any load reduction is profitable for consumers.
- In **case 2 (SBP)** and **3 (BB),** consumers reduce their consumption if $p_s > RR$.
- In **case 2**:
  - *$p_s < RR$ leads to negative DR remuneration.*
- In **case 3**:
  - *They value their unit consumption at the RR because they buy the baseline.*
  - *If $p_s < RR$, they prefer consuming.*

Operators' profits

- With positive market prices :
  - **Generators**

$$\Pi_{Gen} = p_s \,.\, (Q - DR) - CT(Q - DR) + \alpha_k \,.\, p_{eff} \,.\, DR$$

  - **Suppliers**

$$\Pi_{LSP} = (RR - p_s) \,.\, (Q - DR) + Baseline\ (in\ \text{“}case\ 3\text{”})$$

  - **DR Providers**

$$\Pi_{DRP} = (1 - \alpha_k - \beta_i) \,.\, p_{eff} \,.\, DR$$

  - **Consumers**

$$CS = Total\ surplus + \beta_i \,.\, p_{eff} \,.\, DR - Baseline\ (in\ \text{“}case\ 3\text{”})$$

  With DR the load shedding.

- With negative market prices, no DR is observed.

Timing of the game

- **Generators** sell on the market Q-DR volumes at p_s and earn DR transfers to compensate DR profit losses.

- **Suppliers** buy Q-DR volumes at p_s and sell them at retail rate. They perfectly match their supply and demand.

  => *However, they incur profit losses/benefits according to levels of retail rate and p_s.*

- **DR Providers** offer DR services to consumers and bid DR quantities on the market before gate closure.

- **Consumers** buy Q-DR volumes at retail rate and receive transfers from DRP for load-shedding incentives and compensation for surplus losses.

  => *They do not consume DR volumes thus surplus is reduced.*

Data

- We use **EPEX data** for 2014.
  - *Hourly prices and hourly quantities.*
- **Peak period** is defined as hours 5PM to 8PM ("rush hours" from EPEX).
- **Off-peak period** is defined as hours 1AM to 4 AM ("night hours" from EPEX).
- We use these data :
  - *to compute actors' revenues in each pricing schemes.*
  - *to determine the "implicit" break even point (revenues divided by sales or consumed quantities).*
  - *To estimate supply and demand curves to introduce supply costs and consumer surplus (on progress)*

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Intuitions of simulative results

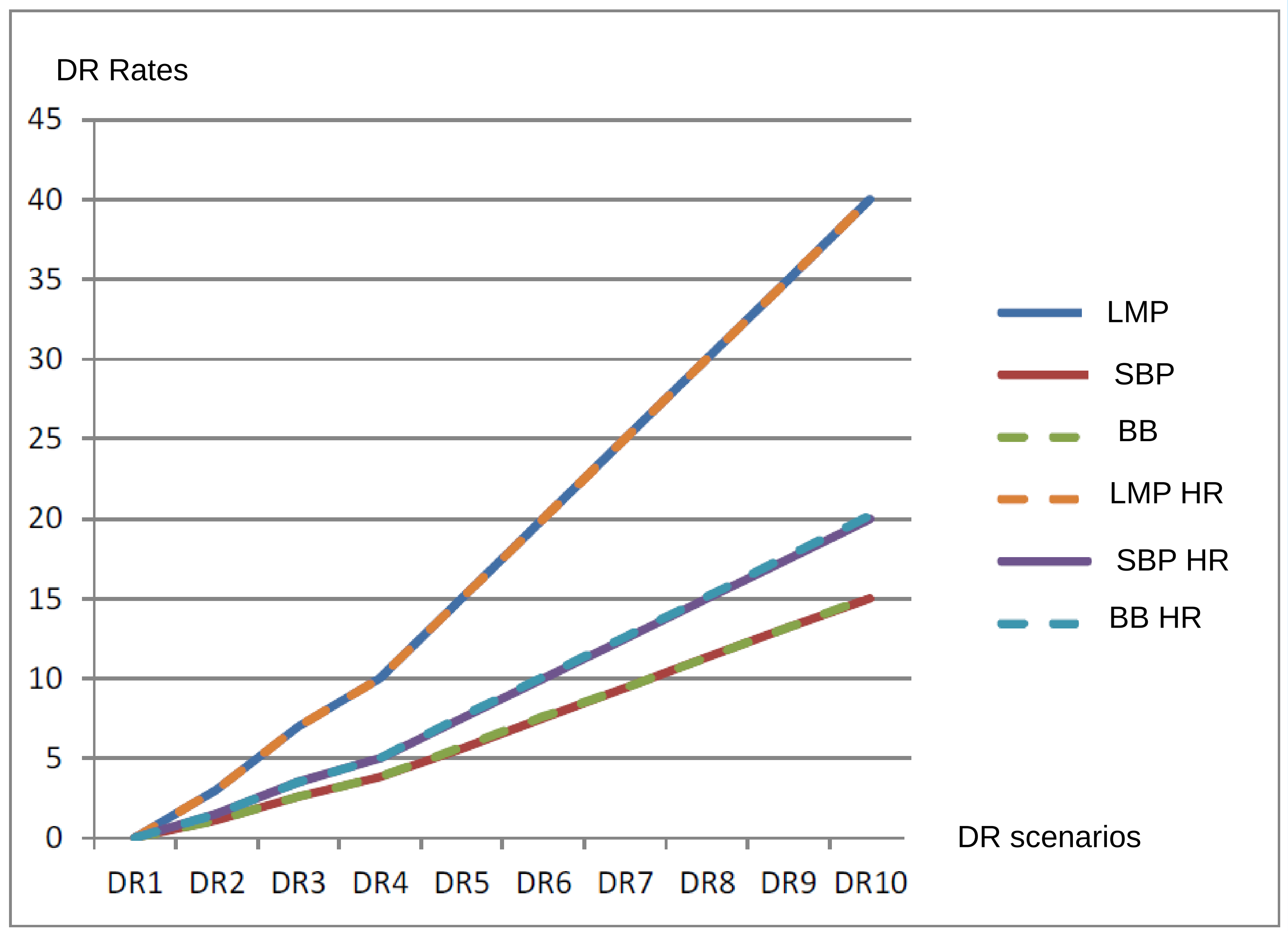
- Generators
  - ❑↘ Direct revenues
  - ❑↗ Potential transfers, “buying baseline” and load-shifting
- Suppliers
  - ❑↘ Direct revenues, load-shifting (if $p_s > RR$)
  - ❑↗ Decrease of costs, in losses, “buying baseline”, load-shifting (if $p_s < RR$)
- DR Providers
  - ❑↘ Transfers
  - ❑↗ Revenues
- Consumers
  - ❑↘ “buying baseline”, load-shifting
  - ❑↗ Decrease of costs, transfers
- Welfare
  - ❑↗ Value induced by DR > negative effect

Results 1 : DR level

- DR quantities are higher under market price (case 1):
  - *Up to 40% of demand for "peak demand".*
  - *For "global hours", 0-10% (DR1-DR4) are consistent with literature.*
- « Buying the baseline » (case 2) and « second best price » (case 3) lead to the same DR levels:
  - *Up to 15% of global demand*
  - *Up to 20% of peak demand*
- But these 2 cases differ by the redistribution of revenue between actors and DR valuation.

- Peak demand represents ± 20% of the global demand (EPEX 2014).
- DR rate is higher in peak periods as profitable conditions are more frequent.

DR rate for each pricing scheme



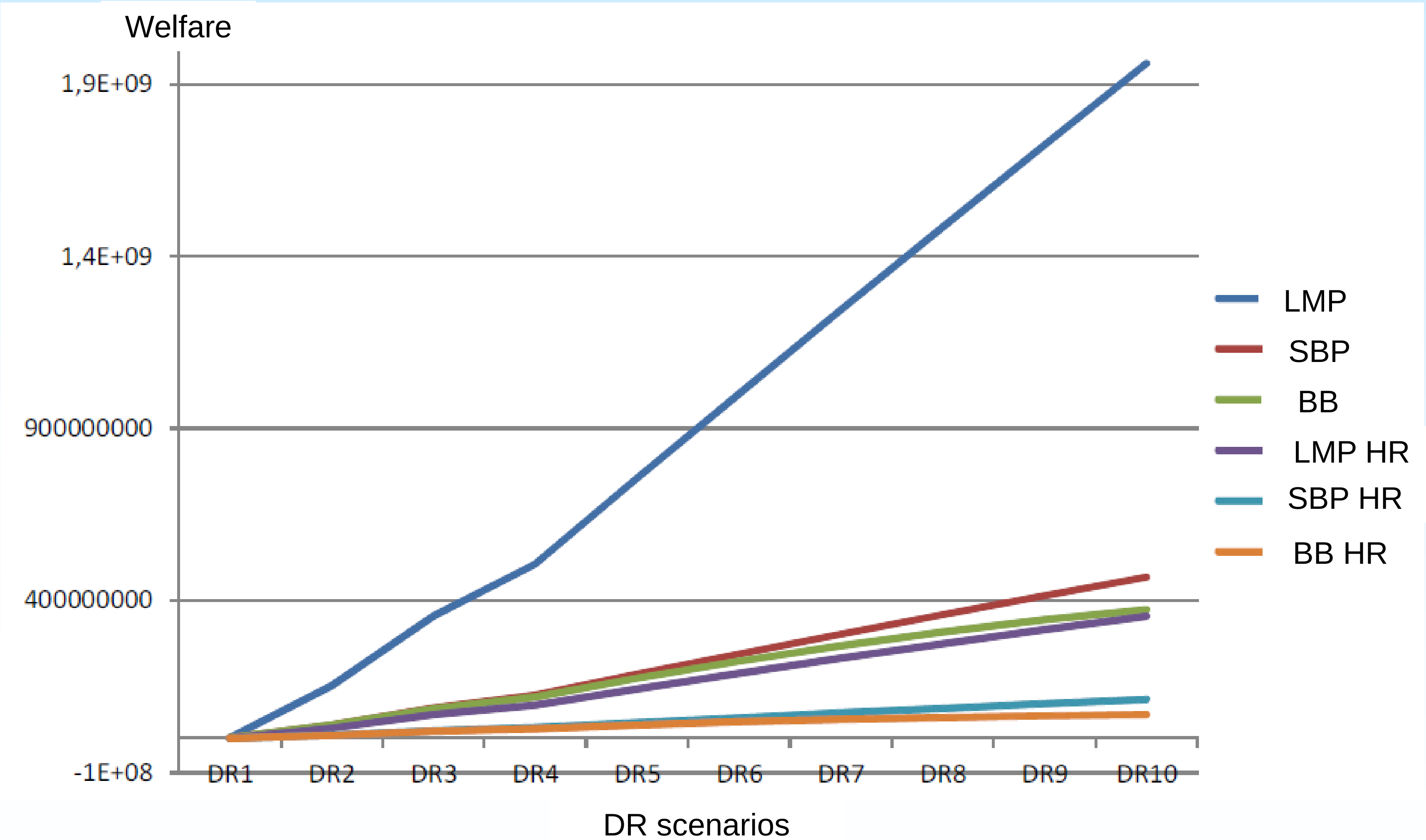
Result 2 : impact on welfare

- Load-shedding increases the welfare; however profitability is always under discussion.

- LMP is the best scheme for welfare.
  - *Intuition : DR often occurs and is paid at market price.*
  - *Break even point up to 48 €/MWh to make DR strategies profitable.*
  - *Break even point up to 8 €/MWh for others schemes (SBP and BB).*

- Break even points are lower if only rush hours are considered.
  - *Up to 5,6€/MWh in LMP case.*
  - *Up to 1,73€/MWh in others cases.*
  - *We are consistent with "demonstrators" : recovering load-shedding costs only during peak hours is not profitable.*
  - *Profitability decreases with load-shifting effect.*

Level of Welfare for DR scenarios



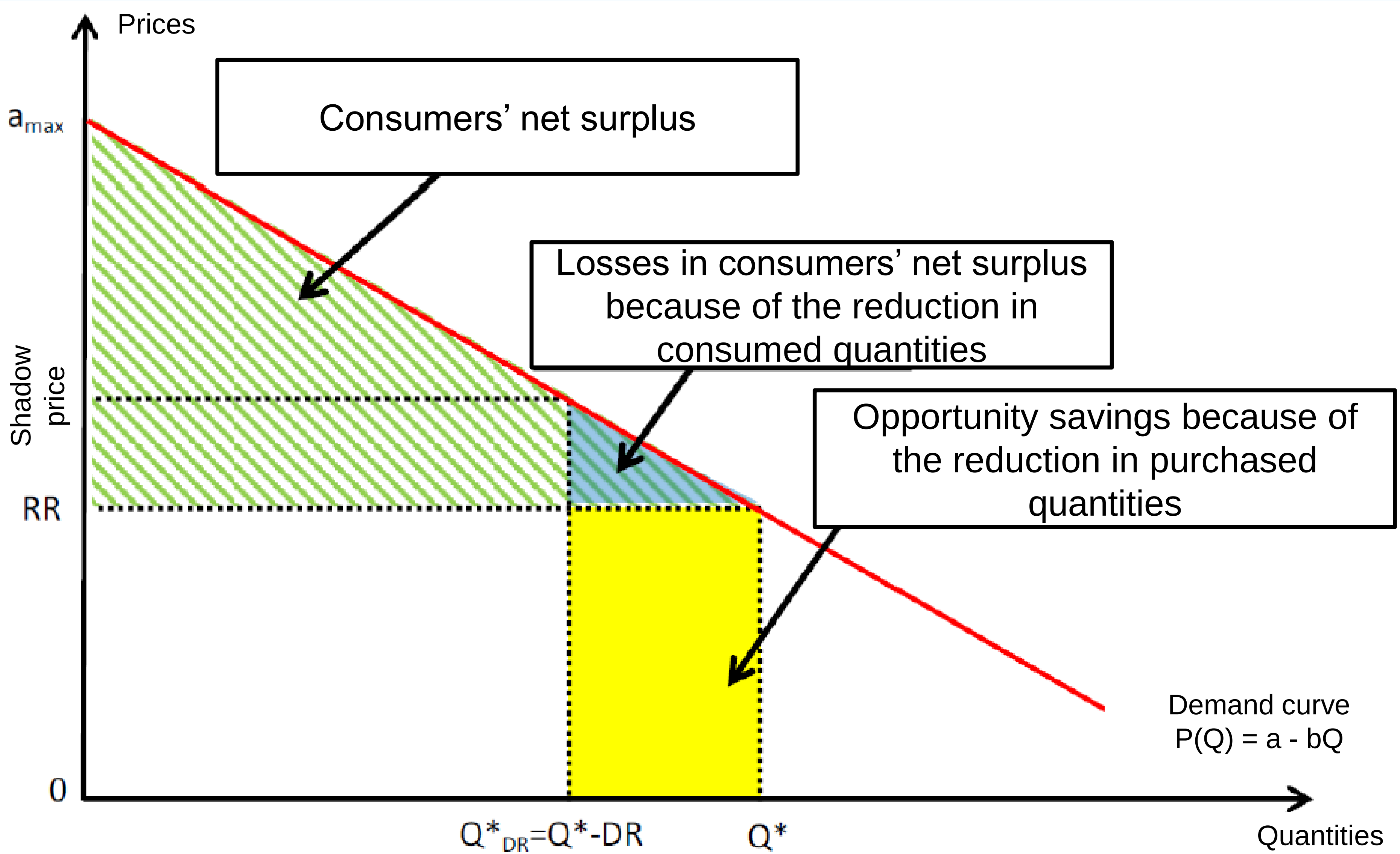
Results 3 : Impact on actors

- For **Generators**, DR often implies transfers towards generators to compensate direct revenue losses (quantity & price effects).
  - *Best scenario is BB if all hours are considered (41€/MWh), LMP and BB for others cases (higher break even point if load-shifting): between 10 and 360€/MWh!! (load-shifting +transfers).*
- **Consumers**' best scenario is LMP (greater DR valued at spot price) and the worse BB (they buy the baseline thus their costs increase).
- **Suppliers**' revenues increase with DR but break even costs are low (up to 8€/MWh); load-shifting reduces their benefits : demand and spot prices increase in off-peak period, erasing savings of the peak period.
- **DRP** have positive revenues (break even point up to 20€/MWh). They are decreasing values of DR because of the marginal revenue of DR is decreasing : further DR is valued at lower prices.

Introduction of costs and consumers' surplus

- Linear supply and demand curves are computed with :
  - *Aggregated data on each hours for each season of consumption.*
  - *Data on supply and demand bids made for each hour.*
- We use backward induction to solve our model :
  - *Consumers buy Q-DR at RR prices => equilibrium on the retail market.*
  - *Suppliers buy Q-DR quantities on the market; DRP valorize the DR volumes considering the scheme of DR pricing.*
  - *Generators face Q-DR demand and serve it at spot price.*
- Suppliers face the risk of RR value; DRP face the risk of zero DR quantities or unprofitable activity because of transfers.
- Generators and consumers bear the risk of imbalances or lower prices on the market. DRP could manage this risk of imbalances for consumers : they keep larger part of DR valuation.

The downstream market (1)



The downstream market (2)

- Transfers (β_i) could compensate consumer's losses in surplus.

  $\Rightarrow$ *DR must be neutral for consumers' comfort.*

- Equilibrium is $Q^* = \dfrac{a - RR}{b}$.
- Surplus losses equal to :

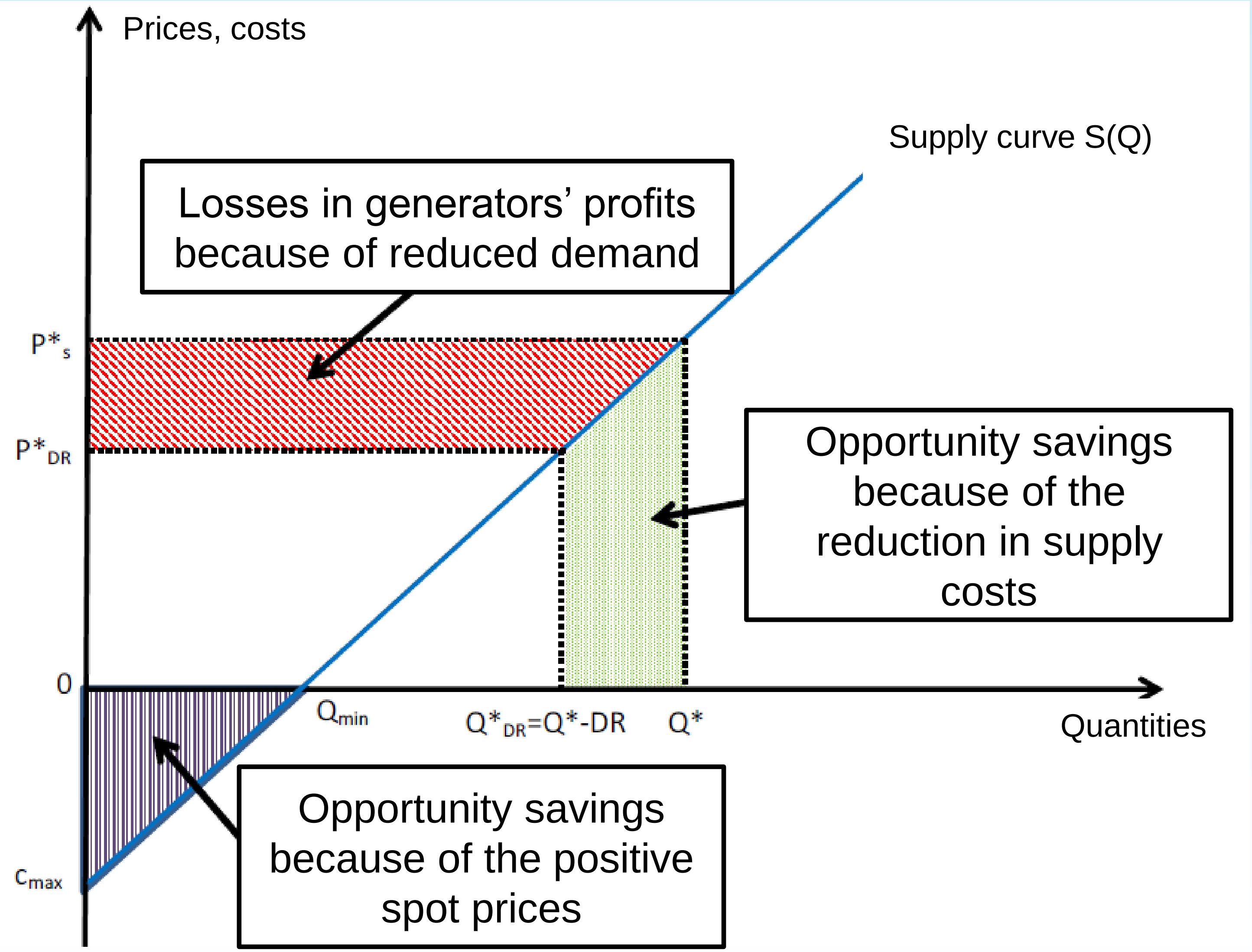
$$\text{Surplus Losses} = \int_{Q^*_{DR}}^{Q^*} P(t)dt - RR \times DR$$

- Opportunity savings increase incentives to implement DR.

  $\Rightarrow$ *In BB case, transfers to compensate surplus losses are necessary as opportunity savings do not exist.*

- Transfers should also be positively correlated with the risk consumers bear (imbalance settlement).

The upstream market



The upstream market (2)

- Transfers (α_i) could compensate losses in generators' profits.

  ⇒ *DR must compensate part of generation costs they must recover and to reduce investment risks.*

- Profit losses equal to :

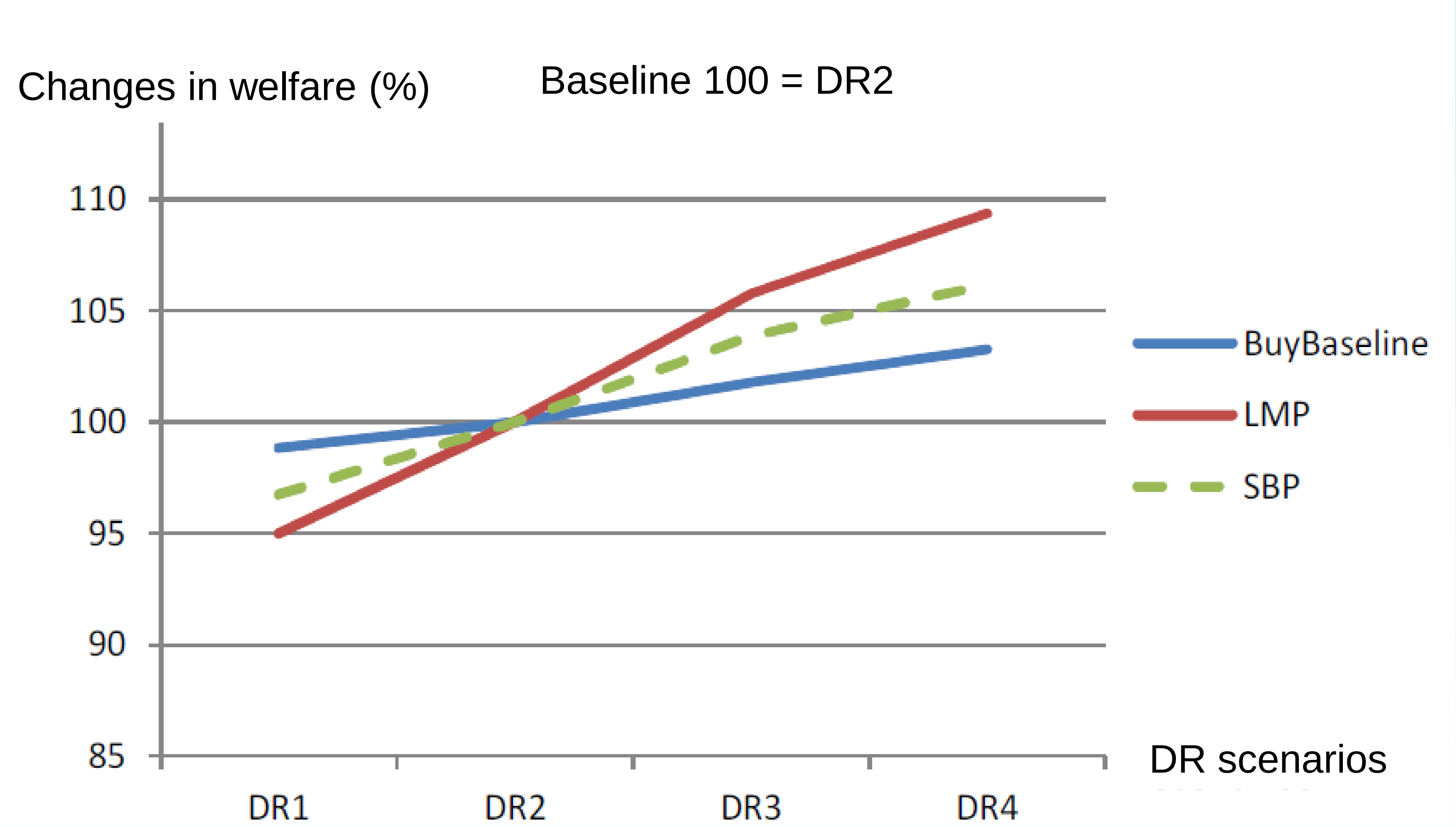
$$\text{Profit Losses} = p_s . Q^* - \left[p^s{}_{DR} . Q^*{}_{DR} + \int_{Q^*{}_{DR}}^{Q^*} S(t)dt \right]$$

- Opportunity savings could reduce the amount of transfers.

  ⇒ *In BB case, transfers to compensate profit losses are not necessary as traded volumes are Q^* at price p_s.*

- Again, transfers should be positively correlated with the risk generators bear (reduction in traded demand as it was forecasted).
- With or without DR, opportunity savings due to positive prices always exist => No effect of this economic value.

Welfare with supply and demand curves



Initial results on global hours

- When all hours are concerned, DR improves the welfare:
  - *Best scenario is LMP because of great valuation of DR.*
  - *SBP follows because of consumer's costs, generators and consumers' losses in profit or surplus are reduced.*
  - *BB is closing off the ranking because of the increase in consumer's costs of supply.*
- DRP break even costs are in a range of 12 to 30€/MWh.

  => DR could be profitable

  => To be confirmed with refined estimations of supply and demand curves.
- However, costs of DR could invert results on welfare because of compensation in savings and losses.

Initial results on rush hours

- For rush hours, DR could have negative effect on welfare:
  - *If load-shifting is reduced, positive effects on welfare always exist.*
  - *If all DR volumes are shifted, negative effects occur.*

    ⇒ *Demonstrators on DR have shown that load-shifting could be of 100% 24h after load-shedding.*

- LMP is always the best pricing scheme except for high values of DR : BB is then preferred as the negative impact on producers' profits is lower and the valuation of DR for consumers encompasses the increase in costs (purchase of the baseline).

    => *This is consistent with the literature on DR.*

- DRP break even costs fluctuate between 2 to 33€/MWh.

    => *Marginal gains of DR decreases : high values of DR are less valued than the previous one… To be confirmed.*

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Conclusions and further developments

- Some conclusions :
  - *Pricing schemes impact the level of available DR.*
  - *DR could improve the welfare if load-shifting is reduced.*
  - *DR is profitable if its costs are moderated and recovered on large periods/per day.*
  - *Some of these results must be "refined".*

- Current works and further developments:
  - *Refined the estimation of demand and supply curves using EPEX data.*
  - *Refined the allocation of DR revenues between actors.*
  - *Introduction of different markets to value DR (intraday spot market and balancing market).*

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Thanks for your attention