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# Making market-based redispatch efficient: How to alter distribution effects without distorting the generation dispatch?

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## Abstract

Market-based redispatch is efficient in short-run but provides perverse long-run incentives. This paper explains such incentives by distribution effects of the tool. Therefore, market-based redispatch is conceptualized as a Coasean bargaining about network capacity. This allows altering distribution effects without impeding the short-term efficiency. Two design adjustments are derived. First, long run incremental cost is introduced next to market-based redispatch, as in the UK. Perverse incentives are removed but the long-run optimum is missed. Second, interruptible network connections with secondary market, known from the gas sector, replace market-based redispatch. This solution is efficient in the short- and long-run.

## 1. Introduction

Market-based redispatch, the default method for managing congestion in the European power transmission networks (EU 2019), is getting increasingly criticized by academics and policy makers alike (cf. BMWK 2020, Dijk & Willems 2011). While leading to an efficient generation and consumption dispatch under the network constraints, i.e. resolving power network congestion efficiently in the short run, market-based redispatch has been argued to provide network users with perverse investment incentives, i.e. be inefficient in the long run (Dijk & Willems 2011, de Vries & Hakvoort 2002, Holmberg & Lazarczyk 2015). For this reason, congestion pricing literature often suggests adopting locational marginal pricing instead (cf. Dijk & Willems 2011, Hakvroot & de Vries 2002). Such pricing represents a generally accepted tool to efficiently address congestion in power networks. However, as seen on the experience of California, changing a system with market-based redispatch into locational marginal pricing implies significant restructuring effort. This makes policy makers reluctant towards adopting locational marginal pricing in practice.

In this paper, we focus on two alternative congestion management models. Both are already implemented in some countries with market-based redispatch and suggested here to optimally resolve network congestion in the short run while avoiding perverse long-run incentives. In the first model, current market-based redispatch is accompanied by long-run incremental cost pricing. This additional network charge is suggested to counteract perverse incentives of market-based redispatch but to be insufficient to provide a socially optimal signal for network-user investment. In the second model, network operator issues firm and interruptible network connections that can be traded at a secondary network capacity market. This model is suggested to substitute market-based redispatch and to optimally allocate network capacity in the short- as well as long-run.

The presented argument is an application of Coase Theorem and the subsequent academic literature discussing its distribution effects. Market-based redispatch is conceptualized in this framework as a Coasean bargaining about scarce power network capacity. It delivers optimal short-term outcome when properly defined network capacity, i.e. the scarce resource, is freely traded and the transaction costs are low (cf. Coase 1960). Furthermore, distribution effects that drive perverse investment incentives can be freely altered without limiting the short-term efficiency of the trading outcome (cf. Demsetz 1972a, 1972b).

The rest of the paper is organized as follows. Section 2 introduces market-based redispatch and identifies income distribution as a source of perverse incentives associated with this tool. In section 3, the first of the two alternative congestion management models is introduced. For this purpose, section 3.1 conceptualizes market-based redispatch as a Coasean bargaining process and describes measures capable of altering its distribution effects. Section 3.2 examines the possibility to practically implement these measures by long-run incremental cost pricing and interruptible network connections. Building on these results, section 4 discusses the second alternative congestion management model, namely interruptible network connections accompanied by a secondary market. Section 5 concludes the paper.

## 2. Income distribution as a source of market-based redispatch problems

This section introduces market-based redispatch and explains the poor economic efficiency of this tool by its distribution effects. For this purpose, locational marginal pricing is introduced as a socially optimal benchmark. Following, the functioning of market-based redispatch as well as the differences against the benchmark are explained.

Locational marginal pricing is a method of applying marginal cost pricing principles on electric power that is transported through the power network system (Bushnell & Stoft, 1997; Schweppe et. al., 1988). The resulting price reflects the marginal system cost of injecting or withdrawing a unit of power at a given node, i.e. location, of a power network. Hence, the price is node specific. It includes not only the marginal cost of system-wide generation adjustment that is caused by the power injection or withdrawal at the studied node, but also the additional network cost that is driven by the associated power flow adjustments. Providing a network user with the locational marginal price allows this user to compare the marginal benefit from the individual power injection/withdrawal with a marginal system cost of such power adjustment. The optimal level of production and consumption, i.e. the optimal dispatch, occurs in result.

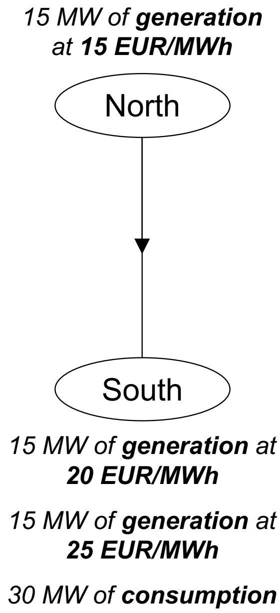


*Figure 1: Model network used for the numerical examples*

To illustrate, consider a two-node network presented in figure 1. Assume generators at the north node of this network to own a total capacity of 15 MW. The marginal cost of producing power at this node is 15 EUR/MWh. Generators at the south node own a total capacity of 30 MW and produce the first 15 MW at a marginal cost of 20 EUR/MWh and the latter 15 MW at a marginal cost of 25 EUR/MWh. For simplicity purposes, consumption is assumed to be constant, i.e. perfectly price inelastic, at 30 MW and located at the south node.

In the absence of any network constraint, Bertrand competition among all generators in the system occurs. As illustrated in figure 2a, it results in an equilibrium system price ($p_u$) of 20 EUR/MWh at which generation in the north supplies 15 MW and the generation in the south other 15 MW. However, what happens when the capacity of the line between the north and the south is below 15 MW, for example only 10 MW. First, generation in the south must fill the gap between the capacity of the line and the demand of the south node, i.e. 30 MW of demand minus 10 MW of supply over the power line from the north when the price exceeds 15 EUR/MWh. Bertrand-Edgeworth model implies an increase in price to 25 EUR/MWh at the south node ($p_S^{LMP}$), where the demand is located. At this price, generation in the south is ready to provide 20 MW in addition to the 10 MW flowing over the power line from the north. Second, production at the north node must be constrained as to avoid congestion on the power line. Generators in the north are ready to produce 15 MW at the price of 25 EUR/MWh. Note that these are indifferent between producing or staying out of the market at the price 15 EUR/MWh. Hence, network operator can satisfy the constraint by setting the price at the north node at this level ($p_n^{LMP}$), i.e. by collecting a network charge equal to 10 EUR/MWh. In result, node-specific locational marginal prices emerge in the system, as illustrated in figure 2b.

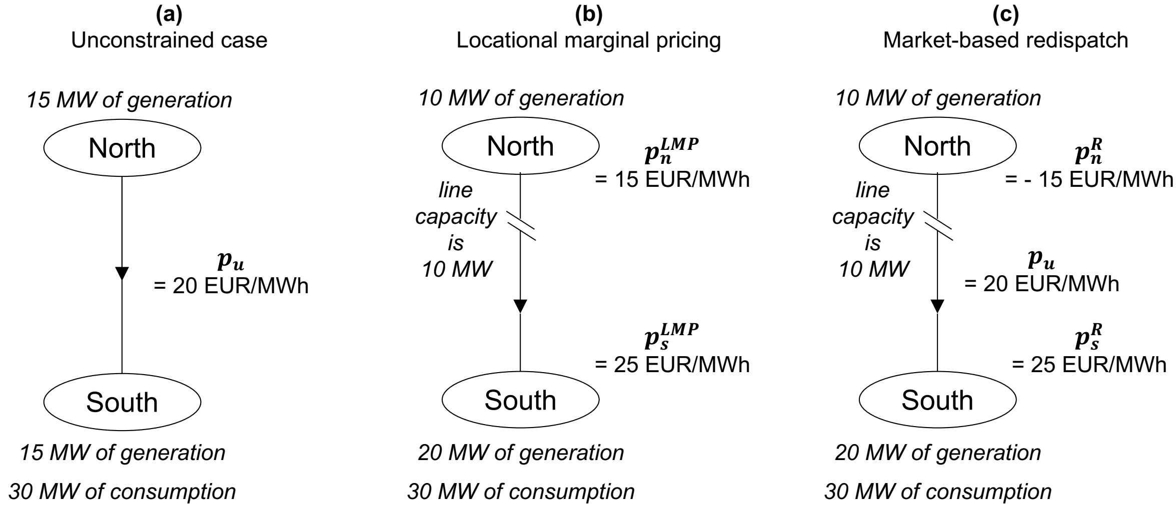


*Figure 2: Power price for the model network in unconstrained case, under locational marginal pricing and market-based redispatch*

Let us now turn to a system with market-based redispatch. Many current national power markets in Europe and elsewhere do not consider network constraints within their clearing process. This is a result of path-dependencies, as these markets were designed at times of sufficient network capacities. Hence, as in the unconstrained case, the output of a typical national power market is driven by the Bertrand competition among all generators in the system. When the dispatch resulting from the clearing of the national market is infeasible due to network constraints, network operator performs market-based redispatch. This represents the default option for the European transmission networks (cf. EU 2019). Referred to as local flexibility market, implementation of this congestion management method is intensely discussed for the distribution networks as well (Anaya & Politt 2014; CEER 2018; Currie et. al. 2011; Esmat et. al. 2018; EC 2016; Kane & Ault 2014; Poudineh & Jamasb 2014, Zhang et. al. 2014). The main advantage of market-based redispatch is seen in its low institutional requirements and easy adoption by the market parties, as it builds up on the processes of the already established national power markets (Hakvroot & de Vries 2002, Knops et. al. 2001). Simply put, it can be implemented quickly when network congestion occurs.

Within market-based redispatch, network operator trades power at the different nodes of the network against the direction of congestion that emerges from the clearing of the national power market. This means that both, national market clearing as well as market-based redispatch take place prior to physical power delivery. To better understand the functioning of market-based redispatch, consider again figure 1. Assuming an unconstrained network, the national market arrives at an equilibrium price of 20 EUR/MWh ($p_u$) where it contracts generation in the north to produce 15 MW and generation in the south the other 15 MW. This means that the line between the two nodes is congested and curtailing 5 MW of generation from the north is necessary. As illustrated in figure 2c, network operator achieves this by *selling* 5 MW to generators in the north at 15 EUR/MWh ($p_n^R$). At this price, generators that were contracted by the national power market are indifferent between fulfilling their obligation by the own generation or by the power provided from the network operator. Aiming to keep power demand and supply in the system balanced, network operator *buys* the same power amount in the south, i.e. 5 MW. This is provided to the network operator at a cost of 25 EUR/MWh ($p_s^R$). The trading activity of the network operator alleviates the constraint in result. Clearly, these trading activities come at cost. The difference between the incomes and expenditures of the network operator, i.e. 10 EUR/MWh ($p_s^R - p_n^R$), represents the cost of market-based redispatch that is typically socialized among the network users.

Given the widespread use of market-based redispatch, its economic efficiency properties are well-understood. It delivers the socially optimal, i.e. lowest cost, dispatch under the given network constraints. Put differently, it is efficient in the short run (Dijk & Willems 2011, Hakvoort & de Vries 2002, Holmberg & Lazarczyk 2015). This can be also seen by comparing figures 2b and 2c. Both, locational marginal pricing and market-based redispatch, activate identical power plants in case of congestion, i.e. 10 MW of generation in the north and 20 MW in the south.

However, the distribution of income within market based redispatch differs from the optimum. This drives perverse investment incentives of network users, which market-based redispatch is increasingly criticized for. To see the point, assume a generator producing at 17 EUR/MWh ($MC_i$) constructing 1 MW of new generation capacity in the network from figure 1. Note that installing an additional MW of generation capacity at a marginal cost of 17 EUR/MWh in line with the Bertrand-Edgeworth model does not affect the national market power price of 20 EUR/MWh. Hence, in an unconstrained case, the marginal surplus of this generator is defined by the difference between the price of the national power market and the own marginal cost of generation and corresponds to 3 EUR/MWh. In locational marginal pricing, the investment at neither of the two nodes influences the respective nodal price. At the north node, the new generator is the most expensive one and incapable to produce a surplus at a price of 15 EUR/MWh, resp. this surplus is negative at -2 EUR/MWh. Hence, the new generator stays out of the market. As opposed to this, the new generator is the cheapest option at the south node and realizes a surplus of 8 EUR/MWh. In a system with market based redispatch, the new generator remains unaffected by the network constraint when located in the south. Put differently, this generator is activated by the national power market as being the cheapest in the south. Herewith, the marginal surplus of unconstrained market equal to 3 EUR/MWh is achieved. However, when located in the north, the national power market contracts all 15 + 1

MW from the generation in the north and only 14 MW from the generation in the south. Given the network constraint equal to 10 MW, the network operator now needs to redispatch 6 instead of 5 MW. Note that the new generator will be the first to accept the redispatch offer of the network operator. This is the case as the power offered by the network operator is sold at 15 EUR/MWh[1] while the own marginal generation cost of producing this power is 17 EUR/MWh. Herewith, market-based redispatch allows for a surplus of 5 EUR/MWh. Table 1 summarizes these results.

| Marginal generator surplus for generator with $MC_i$ = 17 EUR/MWh | Location in the north | Location in the south |
|---|---|---|
| *national power market* *(unconstrained case)* | $p_u - MC_i = 3\ EUR/MWh$ | $p_u - MC_i = 3\ EUR/MWh$ |
| *locational marginal pricing* *(socially optimal benchmark)* | $p_n^{LMP} - MC_i = -2\ EUR/MWh$ | $p_s^{LMP} - MC_i = 8\ EUR/MWh$ |
| *market-based redispatch* | $p_u - p_n^R = 5\ EUR/MWh$ | $p_u - MC_i = 3\ EUR/MWh$ |

*Table 1: Marginal generator surplus within unconstrained market, locational marginal pricing and market-based redispatch for a generator at marginal cost of 17 EUR/MWh.*

Two different conclusions with respect to long-term efficiency of market-based redispatch can be drawn using this table. First, de Vries and Hakvoort (2002) argue that market-based redispatch provides generation with no correct indication of congestion cost and herewith with no network driven locational signals for the new generation investment. A socially optimal incentive drives network-user investment as to release the network congestion. This can be observed on the results of locational marginal pricing. The low locational marginal price in the north turns the generator surplus negative and herewith discourages new investment at this location. This signal reflects the fact that any new generation located in the north is unlikely to reach the consumption in the south, what makes this generation less valuable for the system. At the same time, higher locational marginal price in the south reflects the higher system value for generation at this location. Higher generator surplus results and motivates new generation investment at this location. In comparison, market-based redispatch motivates generation overinvestment in the north, i.e. an export-constrained location, and underinvestment in the south, i.e. an import-constrained location.

Second, market-based redispatch provides perverse incentive to bid strategically at the national power market (Dijk & Willems 2011, Holmberg & Lazarczyk 2015). As indicated in table 1, the income of curtailed generation in the north is not dependent on the marginal

[1] Assuming pay-as-cleared market clearing rule within market-based redispatch. The result of pay-as-bid is likely to be the same when learning effects are assumed.

generation cost of this generation. It is defined as a difference between the price at the central power market and the redispatch bid of the network operator. This allows any network user at a congested node to generate income independent of the own marginal costs if network congestion and the redispatch bid of network operator can be reliably predicted.

To see the point, assume the new generator from above to have a marginal cost of 27 instead of 17 EUR/MWh. Clearly, this generator would generate no surplus in the unconstrained market or under the locational marginal pricing. However, surplus is possible at the north node in market-based redispatch. Assume this generator to bid into the national market strategically below the own marginal cost at e.g. 17 EUR/MWh. What will happen? Expecting the new generator to produce at 17 EUR/MWh, national power market clearing and market-based redispatch occur as above. Herewith, the new generator will accept the redispatch offer of the network operator and arrive at a marginal surplus of 5 EUR/MWh even if the true cost of the generator is much higher than 17 EUR/MWh. Hence, apart from distorting the national power market with strategic bid, this strategic behavior allows for investment of generation that would not occur in the absence of market-based redispatch. Herewith, generation overinvestment in export-constrained locations is enhanced even further. A similar perverse incentive exists also for generation in the south.

To sum up, a typical national power market does not consider network scarcity. Herewith, the dispatch resulting from the market clearing might become infeasible due to network constraints. Market-based redispatch is often implemented as a remedy due to its low institutional requirements and easy adoption by the market parties. On the positive side, this congestion management method delivers the socially optimal dispatch, i.e. resolves network congestion efficiently in the short run. On the negative side, its distribution effects are suboptimal. These promote generation overinvestment in export-constrained locations, i.e. worsen network congestion. Strategic bidding at the national power market might also occur and amplify the perverse investment incentive even further. Therefore, market-based redispatch is increasingly criticized to be inefficient in the long run.

## 3. Altering the income distribution of market-based redispatch

Can the income distribution of market-based redispatch be altered while keeping its short-term efficiency properties intact? This section identifies design adjustments that allow to do so. The argument is an application of the Coase Theorem and the subsequent academic discussion on its distribution effects. Section 3.1 presents this theoretical framework. Section 3.2 discusses the implementation.

### 3.1. Market-based redispatch as a Coasean bargaining about the network capacity

In this section, theoretical measures capable altering the distribution of income within market-based redispatch are introduced. For this purpose, Coase Theorem with the associated theoretical framework is introduced first. Following, market-based redispatch is conceptualized as a Coasean bargaining using this framework. Herewith, design elements driving the distribution of income are identified and measures capable altering these introduced.

If the transaction costs are assumed to be low, Coase Theorem suggests two preconditions to be sufficient for an efficient allocation of a scarce resource. First, tradable property rights for the given resource must be issued. Second, an initial owner of these property rights must be determined. Interestingly, the decision on who exactly becomes the *initial owner* of the property rights is irrelevant for the *final allocation* efficiency. Owning as well as needing a right to use a scarce resource provides an incentive to compare the individual value ascribed to the resource with the value that is ascribed to that resource by others. Such an optimization promotes bargaining among the individuals. This is central for allocating the resource into its most efficient final social use (Coase 1960). However, whereas irrelevant for the final allocation of the resource in the short term, the definition of initial right owner does alternate the distribution of wealth among the stakeholders. The distribution of wealth in turn determines the investment behavior in the market and herewith the long-term efficiency of the system (Mumey 1971, Shoup 1971).

In result, the resource allocation process described by Coase should be thought of as a two-stage optimization process. The stage where the individuals trade with each other represents the *bargaining stage*. This stage defines the final allocation of the resource and hence the short-term efficiency of the system. It reaches an efficient outcome when an initial owner of resource is clearly defined, the property rights are tradable, and transaction costs are limited. This bargaining stage is preceded by an *investment stage*, where the initial allocation of property rights is determined. Stakeholders invest their resources in this stage to alternate their initial allocation of the scarce resource, resp. to develop the best possible negotiating position for the bargaining stage. Profits of an individual are maximized when the marginal cost incurred in the investment stage is optimized against the expected marginal benefit of the bargaining stage (Mumey 1971, Shoup 1971). Stakeholder behavior resulting from this optimization defines the long-term efficiency of the system.

To apply this theoretical framework at market-based redispatch, define the network capacity as a scarce resource that is used for power generation. When congestion occurs, i.e. network capacity becomes scarce, network operator trades this resource with the generators within market-based redispatch. Market-based redispatch can be hence conceptualized as the bargaining stage within the Coasean bargaining framework presented above.

As explained above, network operator sells within market-based redispatch power to generators in the north, i.e. in an export constraint region, in order to lower their utilization of the network. Put differently, network operator buys network capacity from the generators in the north. Hence, power generators active in the export constraint region can be assumed to be the initial network capacity owners within market-based redispatch, i.e. in the bargaining stage.

Recall that network capacity is allocated at the generators by the clearing process of the national power market. Given that the clearing process of this market does not consider the network constraints, every generator with an accepted bid is given a right to use the corresponding network capacity free of charge. Hence, the initial network capacity of a generator at the redispatch market is dependent from the bid that was accepted by the national power market. Note that this bid is limited by the physical properties of the generator's facility, i.e. by the investment decision of the generator. Therefore, the investment stage of market-based redispatch consists of the facility investment decision and the bidding strategy at the national power market.

Herewith, the presented framework can explain the outcomes of market-based redispatch reported in section 2. To illustrate, consider again the network from figure 1 and the new generator from section 2. A rational network user should be expected to optimize marginal cost of the investment stage against the expected marginal revenue of the bargaining stage. The capacity of the new facility was fixed to 1 MW. Furthermore, for simplicity purposes, the new generator did not vary the physical properties of the new generation facility with its location and did not need to bid strategically. Hence, the marginal investment stage cost of a generator can be assumed to be constant across all locations. However, as indicated in table 1, marginal revenue of the generator from market-based redispatch is location dependent. It is the highest at the north node of the network. Hence, the new generator optimizes, i.e. maximizes the difference between, the constant investment stage cost and location dependent bargaining stage revenue by locating the new facility in the north. In other words, market-based redispatch provided a perverse investment incentive to overinvest at an export-constrained location. Furthermore, in line with the presented theoretical framework, this investment decision has no negative effect on the final dispatch of the system. It influences only the initial allocation of the scarce network capacity, i.e. the outcome of the national power market. This increases in the north by the newly installed 1 MW. However, the final allocation of network capacity and herewith the final dispatch emerges from the network capacity trading within market-based redispatch. In line with Coase Theorem, this is efficient as no transaction costs were assumed.

Conceptualization of market-based redispatch as a Coasean bargaining provides an important implication for the further analysis. Its distribution effects can be altered without distorting the optimal short-term efficiency properties. In line with Coase Theorem, market based redispatch will deliver the optimal dispatch when measures addressing its perverse incentives do not distort its trading process. There are three measures emphasized in the academic literature that should allow for this.

First, one might *regulate the investment stage behavior of stakeholders*. Put in the context of figure 1, generation investment and bidding strategies at the north node become regulated as to limit generation overinvestment at this location. Whereas such regulation has been already applied to a certain degree in practice (cf. Palovic et. al. 2022), justifying it within the presented theoretical framework is academically contested. Regulating investment stage behavior is accepted in case of a monopolist (Daly and Grietz 1975), as e.g. in case of regulated power networks. However, regulating behavior at a competitive market, e.g. regulating the investment and market bidding of a competitive generation, is less agreeable. Proponents of regulation argue that optimization of investment stage costs against the bargaining stage revenues demonstrates market power of the given stakeholder. Given that market power can be exercised in competitive market, use of regulation is justified to address this market failure (Demsetz 1971; 1972a). Opponents of regulation suggest such optimization to be possible without market power when transaction costs occur (Daly and Grietz 1975). In this view, optimization of investment stage costs and bargaining stage revenues does not automatically imply a market failure that has to be addressed by a regulatory action.

Second, *initial resource liability can be shifted* at a different stakeholder in a system (Demsetz 1972a). As explained above, generators congesting the network are the initial owners of scarce network capacity in market-based redispatch. This solution implies designating some other stakeholder in a system as an initial network capacity owner. Herewith, a perverse incentive for the current resource owner to perform socially undesirable investment is removed. Who should ideally be selected as an initial network owner? Demsetz (1972a) emphasizes that designating a new initial owner might not avoid the problem of perverse incentives. Similar to the current resource owner, the new owner also has an incentive to optimize the cost of the investment stage against the gains of the bargaining stage. Herewith, new perverse incentives might get introduced into the system. In the context of market-based redispatch, this argument makes a shift of the initial network ownership at the network operator attractive. As a regulated natural monopoly, any newly emerging perverse incentives might be easily addressed by the adjustments to established network regulation. As suggested above, this solution is clearly less contested than regulating investment or bidding behavior of competitive power generation. Implementation of this solution within market-based redispatch is analyzed in detail in section 3.2 below.

Third, one might *redefine the rule of initial resource allocation*. Demsetz (1972b) observes Coasean bargaining to deliver perverse incentives when the resource ownership is poorly defined. He suggests addressing the problem by adjusting the rule that defines the initial allocation of a scarce resource. Note that stakeholder behavior within the investment stage is dependent on this rule. Correspondingly, changing the rule alters the investment behavior of the stakeholders. Herewith, optimization of stakeholders in the investment stage can be used to promote in theory any behavior (cf. Demsetz 1972a, 1972b). Practical implications of this solution are discussed in section 4.

To sum up, conceptualization of market-based redispatch as a Coasean bargaining implies that distribution effects of the tool can be changed without negatively affecting its short-term efficiency. Optimal dispatch will result as long as measures addressing perverse investment incentives do not distort the network allocation of market-based redispatch, i.e. its trading process. Three remedies were derived from this conceptualization. First, regulating the investment of network users at the congested network nodes. Although expected to occur in practice, this solution has been observed to be academically contestable. Second, designating network operator as an initial owner of the network capacity within market-based redispatch. Third, redefining the rule that decides the initial network capacity allocation in market-based redispatch.

### 3.2. Long-run incremental cost pricing and interruptible network connection as remedy

In this section, we examine the possibility to practically implement the second theoretical solution introduced in section 3.1, i.e. to designate the network operator as an initial owner of the network capacity within market-based redispatch. The effect of long-run incremental cost pricing is explored first. Following, implementation by interruptible network connections is analyzed as an alternative.

One option to designate network operator as an initial network owner is to introduce a network charge on the long-run incremental cost basis (LRIC) in addition to market-based redispatch. LRIC is a pricing method applied in different network industries that translates the cost of network expansion caused by new network users into a network charge. It is applied at strategically important nodes of the network and is calculated ex-ante, i.e. prior to any new network connection. Herewith, LRIC is known to prospective network users before these meet the final investment decision. To define the charge, network operator models impact of a new network user, or commonly of a whole network user group, on the network expansion cost within different scenarios. Herewith, the network charge reflects the network topology, i.e. is node-specific. Furthermore, LRIC differs for different network users and is high for facilities that congest the stressed network. However, it might also turn negative when the new facility relieves network congestion. LRIC can take a form of use-of-system or network connection tariff. The use-of-system form is considered in the analysis below. The reason to focus on this form of LRIC is its combined implementation with market-based redispatch in the UK.

Importantly, UK is reported to have made a rather positive experience with market-based redispatch in the past (cf. Hakvoort et. al. 2009, Palovic et. al. 2022).

How does LRIC transfer the initial network ownership at the network operator? Put in a nutshell, LRIC requires every network user to pay the network operator when participating in market-based redispatch. As stated above, LRIC is positive in situations where network user congests the network. Therefore, by paying the charge at network operator, network user in fact buys the permission to congest the network, i.e. to participate at market-based redispatch. Hence, LRIC turns network operator into the initial network owner who sells the scarce network capacity. Importantly, LRIC does not distort trading with redispatch power in market-based redispatch. No network user is constrained in, or excluded from, trading redispatch power. LRIC only alters the marginal cost of scarce network capacity for users located at congested network nodes. Herewith, requirements of the second theoretical solution for the shift in initial network ownership are fulfilled (see section 3.1).

Perverse investment incentives of market-based redispatch are removed in result. As stated, payment of LRIC increases the total cost of network users for acquiring network capacity prior to market-based redispatch. A rational network user optimizes this cost, i.e. LRIC in addition to cost of facility investment and market bidding, against the potential revenues of market-based redispatch. Therefore, market-based redispatch in combination with LRIC generates perverse investment incentives only when the LRIC cost is lower than the revenue from market-based redispatch. In such a case, the remaining surplus compensates the cost of overinvestment and strategic bidding.

To illustrate, consider again the new generator from section 2. This generator has a limited capacity of 1 MW and generates a marginal surplus of 5 EUR per produced MWh when market-based redispatch occurs (see table 1). When implemented in parallel to market-based redispatch, LRIC must be subtracted from this surplus. As discussed above, the new generation in the north alters the national power market to contract 15 + 1 MW in the north and 14 MW in the south. Herewith, the redispatch of the network operator increases from 5 to 6 MW. Given that the redispatch power is sold at the north node for 15 EUR/MWh and bought in the south for 25 EUR/MWh, the new generator causes an additional redispatch cost of 10 EUR/MWh. When charged as LRIC, i.e. substracted from the surplus of market-based redispatch, the net surplus equal to -5 EUR/MWh results, as indicated in table 2. Comparing this result to other scenarios listed in table 2 indicates that the perverse investment incentive of market-based redispatch is removed but the social optimum missed.

| Marginal generator surplus for generator with $MC_i$ = 17 EUR/MWh | Location in the north | Location in the south |
|---|---|---|

| | | |
|---|---|---|
| *national power market* (unconstrained case) | $p_u - MC_i = 3\ EUR/MWh$ | $p_u - MC_i = 3\ EUR/MWh$ |
| *locational marginal pricing* (socially optimal benchmark) | $p_n^{LMP} - MC_i = -2\ EUR/MWh$ | $p_s^{LMP} - MC_i = 8\ EUR/MWh$ |
| *market-based redispatch* | $p_u - p_n^R = 5\ EUR/MWh$ | $p_u - MC_i = 3\ EUR/MWh$ |
| *market-based redispatch with LRIC* | $p_u - p_n^R - LRIC = p_u - p_s^R = -5\ EUR/MWh$ | $p_u - MC_i = 3\ EUR/MWh$ |

*Table 2: The effect of LRIC on marginal generator surplus for a generator with a marginal cost of 17 EUR/MWh that is located in the network from figure 1.*

Given the numerical result, can LRIC drop below the marginal surplus of market-based redispatch? In a competitive market, this is never the case. The marginal surplus of export-constrained generator, i.e. in the north, from market-based redispatch is defined as a difference between the price of an unconstrained market and the price required by the network operator for redispatch power, i.e $p_u - p_n^R$ (see section 2). LRIC reflects the network cost of market-based redispatch. This network cost is defined as a difference between income from selling redispatch power in the north and buying redispatch power in the south, i.e. $p_s^R - p_n^R$. Hence, LRIC falls below the marginal generator surplus when the redispatch power price at the import constrained node, i.e. in the south, drops below the price of unconstrained market, i.e. $p_s^R - p_n^R < p_u - p_n^R \Rightarrow p_s^R < p_u$. It is easy to realize that competitive markets never deliver this outcome. Recall from section 2 that the equilibrium price of the national power market is a result of Bertrand competition. Herewith, generators providing redispatch power at the import-constrained node, i.e. the ones that national power market did not contract, have per definition marginal cost that is above or at best equal to the price of the national power market.

To sum up, introducing LRIC in addition to market-based redispatch clearly counteracts its perverse investment incentives. However, comparing this solution to locational marginal pricing (see table 2) clearly indicates that incentives of this solution are suboptimal.

Another option to designate network operator as the initial network capacity owner is the use of constrained network connection. Constrained network connection is a rather new tool in the power sector. Referred to as smart connection agreements, it is currently implemented only at a very limited scale or within demonstration projects in France and the UK (Furusawa et. al. 2019). As opposed to this, these are regularly used to manage congestion in the European and US gas networks. Constrained network connection is typically voluntary. When meeting an agreement with a network user, network operator specifies the properties of expected interruptions, such as their frequency, duration, or volume. Given the network benefits of the constrained connection, newly connecting network user capacities can be connected at a lower cost or at a faster pace to the network. Alternatively, network users can fall back at a firm non-interruptible network connection. Firm connections are charged at a higher price or only available after the network expansion.

Note that acquiring a firm non-interruptible network connection in this model, as LRIC above, requires network user to pay the network operator. As discussed above, such setup allows network operator to decide on the network capacity when scarce, i.e. turns network operator into the initial network owner.

The model of interruptible network connections differs from LRIC in one aspect significantly though. It allows network user to reduce payment at the network operator, resp. to waive the payment, in exchange for network-driven curtailment. Accelerated network access in this context represents only a special case with infinitely high network expansion cost, resp. cost of a firm network connection. Network user either carries the cost of firm connection, i.e. acquires scarce network capacity prior to market-based redispatch at a cost, or forgoes the expected revenue of market-based redispatch by interruptible network connection. As shown above (see table 2), a rational network user will opt for the latter when the charge is driven by the congestion cost of the network.

A loss in short-term efficiency results. Market-based redispatch was argued in line with Coase Theorem to reach the optimal final dispatch in the short run due to its reliance on market mechanism when allocating the scarce network capacity. Introducing interruptible connection in this context removes network users from this market. Put differently network operator can alter power withdrawal or injection of network users outside of the market-based redispatch. This undermines the allocative function of trading within market-based redispatch.

Clearly, network operator might be incentivized to compensate this inefficiency by comparing the opportunity cost of interruptible connection to the cost of trading at the redispatch market, i.e. to optimize across the two congestion management tools. However, such an optimization is inferior to the one of market-based redispatch. A rational network user voluntarily accepts interruptible connection when the discount provided by the network operator equals or exceeds the forgone revenue of curtailment. Hence, discount provided by the network operator indicates only the upper limit of the network user value ascribed to the curtailed network capacity. Network operator has no information on the exact network user value ascribed to the network. As opposed to this, network users reveal their true valuation of the network capacity when bidding within market-based redispatch. Hence, merit order of market-based redispatch contains more information than the merit order constructed by the network operator when combining interruptible connections with market-based redispatch.

To illustrate, assume the new generator from section 2 to locate at the north node of the network from figure 1 and have an unknown marginal generation cost. Furthermore, for simplicity purposes, assume network operator to offer firm connection in line with the LRIC example from above at a cost of 10 EUR/MWh. Given the clearing price of national market at 20 EUR/MWh (see section 2), new generator opts for firm access when the marginal generation cost stays below 10 EUR/MWh. Otherwise, interruptible network connection is preferred. Herewith, network operator has no information on the exact marginal generation cost of the new generator. The network connection decision of the generator only indicates whether this cost lies above or below 10 EUR/MWh. Hence, no comparison to offers made within market-based redispatch at 15 EUR/MWh is possible. Inefficiency in the final dispatch is likely to occur in result. As opposed to this, market-based redispatch will efficiently allocate this new generator into the final dispatch. Recall that generators with higher marginal cost bid higher for becoming redispatched. Therefore, the new generator will get curtailed when having a marginal generation cost above 15 EUR/MWh and produce when this cost is lower.

To sum up, two congestion management tools have been suggested to designate network operator as an initial network capacity owner and herewith to address perverse investment incentives of market-based redispatch. Long-run incremental cost pricing is currently used in the UK in addition to market-based redispatch. This combination has been suggested to keep the short-term efficiency of market-based redispatch intact and to counteract the perverse investment incentives. However, it was also shown to miss the social long-run optimum. Interruptible network connection, as currently discussed in France and the UK, were suggested to have the same effect on the investment incentives of market-based redispatch. However, use of interruptible connections alters the final power dispatch of market-based redispatch and hence undermines its allocative efficiency, i.e. loss in short-term efficiency occurs.

## 4. Interruptible connections with secondary market as an alternative

In this section, we discuss interruptible network connections as a substitute to market-based redispatch. When combined with a secondary market for trading unused network capacities, as common in the gas sector, interruptible network connections are suggested to become a stand-alone Coasean bargaining process. This is more efficient than market-based redispatch.

As stated above, interruptible network connections are commonly used to manage network congestion in the gas networks (cf. EC 2007, NERA 2002). These are in this sector accompanied with a secondary market. At this market, sometimes also called a capacity release market, network users trade unused firm and interruptible connections among each other. Herewith, a new bargaining stage for trading network capacity is introduced. This has two important implications. First, interruptible connections with secondary market do not adjust the design of market-based redispatch. Instead, this model represents a stand-alone congestion management mechanism that substitutes market-based redispatch. Second, designating some other stakeholder than network operator as an initial network owner is possible by grandfathering the firm network access within this model. Herewith, the third theoretical solution from section 3.1 can be easily implemented. Put differently, designating network operator as an initial network owner by interruptible network connections represents only a special implementation case of the third theoretical solution.

This brings up the question, whether network operator should initially own the network? Put differently, can short- and long-run allocation of network be improved by designating some other stakeholder as an initial network owner? The academic literature concerned with Coase Theorem provides no clear guidance on whom to designate as an initial network owner, resp. how to determine the optimal initial allocation of a scarce resource. To explain, this literature focuses on external effects of resource use and their internalization (cf. Coase 1960). In this context, defining a liability rule that promots global optimum, i.e. also an efficient resource allocation in the long run, proves to be difficult (cf. Demsetz 1972a, 1972b).

Fortunately, problem discussed in this paper is of somewhat simpler nature. Network use has been conceptualized as an external effect of power production and consumption to make the implications of the presented theoretical framework clear. However, network capacity is a factor of production with a clearly defined social cost. This corresponds to the opportunity cost of resources that have been used for power network construction and operation. Herewith, the global optimum of the studied system can be defined.

As for the short-term optimum, designating network operator as an initial network owner does not limit the allocative function of the secondary capacity market. Consider a network user in need of a firm network connection. This can either purchase it from the network operator or from other network users at the secondary market. Offer of the network operator, which is driven by the network expansion cost, represents an opportunity cost to purchasing an firm connection from other network users at the market. Given the demand for firm network connection and the associated secondary market price, firm connections owned by the network users have an opportunity cost that promotes allocating scarce network capacity into the most efficient final social use (see section 3.1).

To illustrate, consider again the new generator with unknown marginal generation cost discussed in section 3.2. At the secondary market, established generators in the north are ready to sell their firm connection when their forgone surplus at national power market is compensated for. Given that these generators compete, firm network capacity is offered at the secondary market at 5 EUR/MWh. Hence, when characterized by a marginal generation cost below 15 EUR/MWh, the new generator will opt for purchasing firm connection from other generators in the north. Otherwise, interruptible connection is accepted from the network operator. In any of the two scenarios, the final dispatch is optimal.

As for the long-term efficiency, no perverse investment incentives for network users exist when initial network capacity is allocated at the network operator (see section 3.2). However, perverse incentives on behalf of the network operator might emerge (see section 3.1). Note that the socially optimal network investment can be reached only with the help of network regulation. When unregulated, network operator might have an incentive to limit available network capacity when scarce at the secondary market. Hence, the socially optimal network investment might be suboptimal for the network operator. However, this deficit does not seem to result from perverse investment incentives of the proposed solution. Instead, it can be reasoned by the natural monopoly of the network operator. If there would be a perfect competition, higher price for network capacity would drive additional network investment.

Indeed, socially optimal network investment should emerge. This occurs when the social cost of network is optimized against the value ascribed to the network by the network users (see section 2). Such an optimization is promoted by secondary capacity market. Given that bids at this market correspond to the forgone surplus of network users from curtailment, equilibrium price of the secondary market represents the social value of network expansion. At the same time, firm connection from network operator, which is based on the social cost of this resource, represents an opportunity cost to purchasing unused network connections offered at the secondary market. Hence, demand-driven network expansion under interruptible network connections with a secondary market results in a socially optimal network investment.

To sum up, this section presents interruptible network connections with secondary market as a stand-alone congestion management mechanism and suggests it to achieve the optimal network capacity allocation in the short- and long-run. For this purpose, network capacity is defined as a factor of production that has a clearly defined social cost. The offer of the network operator to provide a firm connection at this cost represents an opportunity cost to purchasing unused firm connection from other network users at a secondary market. Given that bids into this market correspond to the forgone surplus of network users under curtailment, secondary market not only delivers the optimal dispatch in the short-term, but also indicates the social value of the network through its equilibrium price. Optimal network investment results when perfect competition in network investment is assumed, resp. when the network operator is regulated. Furthermore, designating network operator as an initial network owner removes perverse investment incentives for network users.

## 5. Conclusion

National power markets rarely consider network scarcity in their clearing process. Herewith, network constraints might deem the resulting power dispatch infeasible. Market-based redispatch is a congestion management mechanism that is often implemented as a remedy due to its low institutional requirements and easy adoption by the market parties. In fact, it is prescribed for managing congestion in the transmission networks by the European Commission (EU 2019) and, under different headings, intensely discussed also as an option for the distribution networks (cf. CEER 2018, EU 2016).

On the one hand, market-based redispatch delivers the socially optimal dispatch, i.e. resolves network congestion efficiently in the short run. On the other hand, its distribution effects are suboptimal. These promote generation overinvestment in export-constrained locations (Hakvoort & de Vries 2002) and strategic bidding at the national power market (Dijk & Willems 2011, Holmberg & Lazarczyk 2015). An increase in network congestion results from both behaviors in the long run. Therefore, market-based redispatch is getting increasingly criticized not only among the academics (cf. BMWK 2020). Locational marginal pricing is often suggested as an alternative that optimally manages congestion (cf. Dijk & Willems 2011, Hakvroot & de Vries 2002). However, implementation of this tool requires a significant sector restructuring, what makes policy makers reluctant.

This paper studies two design adjustments to market-based redispatch. Both adjustments address perverse long-run incentives of this tool while keeping its short-term economic efficiency properties intact. To develop these alternative designs, market-based redispatch is conceptualized as a Coasean bargaining about scarce power network capacity. In line with Coase Theorem and the subsequent academic literature (cf. Demsetz 1972a, 1972b), distribution effects of such bargaining process can be freely altered as to address any perverse long-run incentives. At the same time, the final resource allocation, i.e. final network capacity dispatch in our case, is optimal as long as it emerges from free trade with properly defined resource rights and low transaction costs.

A measure implied by the corresponding literature suggests designating network operator during congestion as an initial network owner, who is paid for the access to the scarce network. Network users congesting the network are observed to be the initial owners of the scarce network capacity within the current model. Shifting the initial network ownership away from the network users makes this resource costly for the network users during congestion. Herewith, a perverse incentive to overuse this resource when scarce is reduced. In practice, this is suggested to be achieved by introducing long-run incremental cost pricing in addition to market-based redispatch. Such combination is for example practiced in the UK. The additional network charge has no negative effect on network capacity trading within market-based redispatch and argued to fully remove its perverse long-run incentives. Efficient in the short-run and improving the long-term efficiency of market-based redispatch, this model is shown to miss the social optimum in the long-run though.

Accompanying market-based redispatch by interruptible network connections represents an alternative implementation for designating network operator as an initial network owner. Implementation of this model is currently discussed in France and the UK (cf. Furusawa et. al. 2019). However, interruptible contracts are observed to interfere with the dispatch resulting from market-based redispatch as curtailment of network users becomes possible also outside of the market-based redispatch. This clearly limits the short-term efficiency of the final dispatch. Nevertheless, interruptible network connections are also commonly used to manage congestion in the gas networks (cf. EC 2007, NERA 2002), where these are accompanied by a secondary market. This market allows the network users to trade their unused firm and interruptible connections amongst each other.

Within the studied theoretical framework, such implementation constitutes a stand-alone Coasean bargaining process that can fully substitute market-based redispatch. It reaches optimal final dispatch that is derived from free trade of network capacity, i.e. of firm and interruptible network connections, at the secondary market. Furthermore, offer of the network operator to provide new firm network connections, i.e. to expand the network capacity, represents an opportunity cost to purchasing capacity at the secondary market. Network users compare it to the offers of other network users at the secondary market and herewith to their individual valuation of network capacity. The resulting demand of network users for the firm connection from network operator indicates the social value of the network. Network operator compares it to the cost of network investment, i.e to the social cost of the network. Optimal network investment results when perfect competition among network operators is assumed, resp. when the network operator is regulated. In addition, network operator decides in this model on the amount of firm and interruptible network capacity that is made available to network users. As in case of long-run incremental cost pricing, this setup prevents emergence of perverse investment incentives on behalf of the network users. Hence, optimal network capacity allocation in the short- and long-run occurs.

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