The birth of a EUropean Distributed EnErgy Partnership
that will help the large-scale implementation of distributed energy resources in Europe

Network investments, network regulation and DSO-DER interaction

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General purpose of this document

The advantages of decentralized energy resources (DER) in electricity networks are due to a number of aspects, such as environmental efficiency, energy efficiency, resiliency and capacity investment deferral at various grid levels. As many of these benefits are harvested at other than the DER sites, the optimal investment level in DER crucially depends on how effectively the regulation framework for DER can identify, incentivize and allocate the correct revenues and costs for the agents in the energy network.
A particularly relevant issue in this respect is to what extent and in which form the regulator should intervene in the relationship between the distribution system operator (DSO) and the DER investment owner. The current regulatory situation in Europe shows no clear trends in this matter, as varying levels of centralization are observed in the network regulation.
We present a formal model to investigate three prevalent scenarios; the full DSO-DER integration, a decentralized DSO scenario and centralized scenario with parallel regulation of both DSO and DER investments. For each scenario, we determine optimal investment policies for the DSO and DER owner under regulatory control or incentives. The evaluation criterion is the generated welfare effects, measured as the proportion of socially profitable investments that are undertaken.
The first scenario, corresponding to a situation where the unbundling requirement on the DSO is relaxed, shows the highest investment rates. The DSO internalizes the investment and the loss of investment is due to rationing by the regulator due to information problems.
The second scenario simplifies the regulation by delegation to the DSO to handle DG issues, but the results are characterized by lower investments and some distortions in the providership. Hence, the simplicity comes at a cost in this sense.
The third scenario provides the regulator with the added opportunity to contract separately with both the DSO and the DG. This arrangement brings several advantages for the investment incentives to limit costs, but it is shown that the relative profitability of investments at the two levels will crucially depend on the structure of this regulation, e.g. the role of the DG 'bid' in the regulation and the DSO right to initiate investments.
The formal model is currently only investigating substitute investments, but extensions are outlined for complementary investments, uncertainty and more advanced developments of the last scenario. We believe that the preliminary findings in the report both are of policy and scientific interest and that the structured model provide a vehicle to access the complex domain.

This report is the second in a series of three reports to investigate the economic regulation of DER in Europe to inspire an informed discussion on the challenges and potential innovative ways to cope with them.

A draft of this report was submitted for discussion at the EU-DEEP regulatory working group (EU-DEEP RWG).

Disclaimer:

Examples and cases in this document are selected for illustration only and are not intended as examples of regulatory compliance to national or European law for which legal advice should be sought. No part of the regulatory documentation has been subject to the review of the national regulators involved and the viewpoints in the document represent only those of the authors that also assume the responsibility for all possible errors.

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1 Introduction

1.1 Aim

The current report investigates the interaction between the economic regulation and task allocation of distribution system operations (DSO), on the one hand, and the introduction of distributed energy resources (DER) or decentralized generation (DG) on the other hand. We develop simple models of incentive provision and coordination under asymmetric information and choice to investigate key organizational and regulatory issues like integration versus separation of DSO and DER activities and the centralized or decentralized regulation of the DSO and DER activities.

The underlying idea of the report is that it typically is more important from a welfare economic perspective to get the organizational and structural aspects of regulation right than to fine tune the regulation within a given structure to limit the information rents that the parties can extract.

1.2 DER characteristics

Decentralized generation interacts with electricity distribution in many ways. In particular, it interacts with the need to make new investments to fulfill demand on the consumer side or to accommodate new generation in the DG side. Likewise it affects losses in the network, voltage control etc with in turn affect the necessary network investments. Engineering models can be used to study such interactions in more details as discussed in Agrell and Bogetoft (2006, EU-DEEP Report).

1.3 Substitutes or complements

From a general economic perspective, an important observation is that DG and DSO investments interact and that that DG can both substitute and complement DSO investments depending on the type of DG, the location in the grid, the characteristics of the grid etc. From a welfare economic perspective this raises the question of how to coordinate the investments such that at the most one of two possible substitutes investments are undertaken and that neither or both of two complementary investments are implemented.

1.4 Unbundling revisited?

From a regulatory and organization perspective, this raises crucial questions about the costs of ownership unbundling of DSO and DG assets on the one hand and the possibility of a regulator to coordinate the DG and DSO activities by individual regulation targeted at the DSO and DG levels respectively. As the emphasis in the current presentation is put on the welfare effects of specific investments in the network operations, we do not address other effects on e.g. the price formation in the retail market, postponement of centralized generation investments or potential problems of enforcing non-discriminatory access resulting from alternative organizations of unbundling. The institutional solution chosen in the IEM directive goes beyond the scope of this paper and we leave the reader with some informed arguments about the issue, without providing any absolute policy recommendations.

1.5 Decentralized information

Anther key characteristic is the decentralized / asymmetric information about investments costs in both the DG and the DSO levels. Decentralized information leads to incentive problems where the parties may not make the socially optimal decision unless they are privately incentivized. The parties may – pursuing private interests like profit maximization - "lie" and "shirk" since their pre-contractual information is private and their post-contractual actions cannot be precisely monitored.

The asymmetric information and the need to motivate private parties to make socially attractive decisions constitute the core of modern regulation theory, cf Laffont and Tirole (1993). The regulator-principal is assumed to have inferior information about the DSO-agent's costs. Modern regulatory regimes such as the yardstick regimes in Shleifer 1985, and Armstrong, Cowan and Vickers (1994) or the popular price and revenue cap systems, reviewed in Burns and Estache (1999), are remedies to this problem.

The problems of asymmetric information will tend to be aggravated with the introduction of DG. The possibility for the regulator to bridge the information gap through generic revelation regimes or through comparative information on DSO costs is limited since the impact of DG is highly case specific. The resulting avoided cost will depend on on characteristics of the load, the incumbent network, the spatial and network location and timing of the DG installation, cf. Deuse (x).

Analogously, the regulator – or the DSO for that matter – will have imperfect information of the costs to the DG installer. In particular, the private profitability to the DG installer depends also on the private value derived directly from the DG, i.e. elimination of industrial excess heat. Due to the diversity of the DG ownerships, sectors and underlying processes, any attempt to elicit the individual value of the installation is likely to fail.

1.6 Structures

To get basic insights into the characteristics of different regulations and organizational forms we shall investigate three possible arrangements (scenarios) under different possible conditions.

The possible regulations involves an integrated solution, where the DSO and DG operations are fully integrated, a centralized (but separated) solution where the regulator regulates the DSO and DG activities in parallel and a decentralized (but separated) solution where the regulator contracts with the DSO and the DSO contracts with DG. The three solutions are illustrated in Figure 1-1 below.

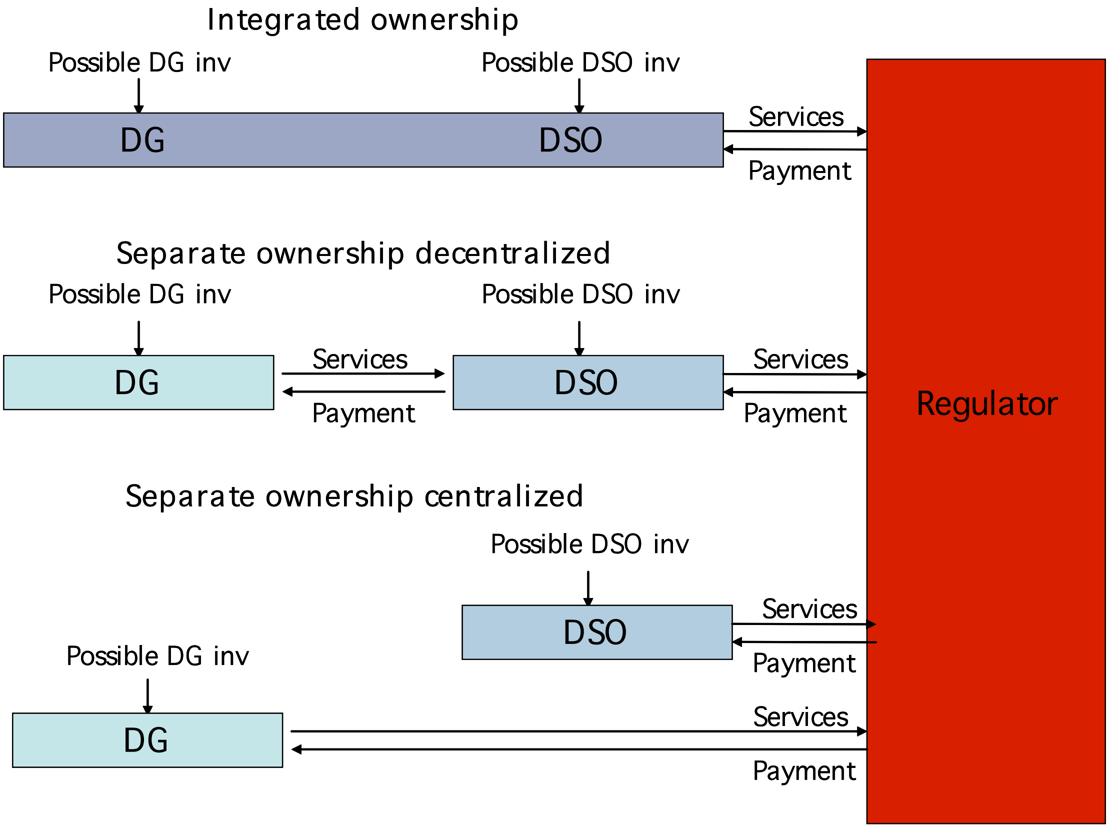

Figure 1-1 Alternative ownership and regulation structures

1.7 Avoided network investments

Our interest here is limited to the interaction between the DSO and the DG investments, essentially the distribution capacity deferral effects (D) in the Iannucci et al. (2003) framework. As we consider a short time horizon without growth, the terms deferred and avoided investments become equivalent. The two possible settings are when DG and DSO investments are *substitutes* and *complements* respectively. We investigate the case of substitutes here and the case of complements in an accompanying paper.

Before turning to the analysis and comparison of the possible scenarios, we note that one can also distinguish between *static and dynamic models*. In the former, the DG and DSO are exogenously matched while in the latter situation, they are matched endogenously, such that a DSO with high network investment costs can team up with DG that is cheap to implement. Again, the static versus dynamic perspectives are both relevant depending on the nature of the DG and the location specificity of the DG in question. We shall focus on the static aspects here and leave the dynamic and matching issues to another paper.

1.8 Outline

We commence by developing a stylized model of the DSO and DG investments and the informational asymmetries involved. Next, we investigate the six possible structures in turn. In the final chapter, we discuss the interpretation of our stylized results in the context of real DSO and DG activities, we conclude and we give suggestions for future research.

2 Model

We consider a simple case with one regulator, one DSO and one DG. The DSO and the DG can both make investments, the costs of which are private information to the DSO and DG respectively. The investments are either substitutes or complements. One can think of them as capacity reinforcement and capacity expansion of the network, respectively. We shall now formalize in the simplest possible way without losing key properties of the situations or the solution.

2.1 Regulator

The aim of the regulator is to maximize social welfare. In a situation where new investments are possible at the DG and DSO levels, respectively, we may assume that the extra value generated if these investments are undertaken is V>0. If the regulator – as a representative for the consumers – has to pay a total transfer T (=R+S) as compensation to the DSO and DG, e.g. by increasing the revenue cap, the social welfare improvement is

$$W = V - T$$

The objective of the regulator is to maximize the expected value of W.

Note that it follows from the postulated objective of the regulator that he explicitly trades off the benefit derived from the costs of ensuring these. For sufficiently high values of V, however, this accommodates the objective of simply minimizing the expected costs of making the necessary DSO and DG activities. In such cases, we are close to the implicit assumption in much regulation, namely that demand is basically given and price inelastic and the aim is to fulfill demand at the least possible costs.

Another variant of the objective could be to maximize consumer surplus as given by W plus the DSO and DG surpluses as given by the expected profits below. In that case, and since the distribution of surplus would not matter, any solution that ensures investments as long as this is possible at costs less than V and that in the case of substitutes ensures that the investment is allocated to the least cost level, whether the DSO or DG level, will be optimal. It is easy to see that such a solution is possible is possible in the case of integrated DSO and DG, while the situations with separate ownership will always lead to some misallocation of the investments due to the asymmetric information.

2.2 DSO

The DSO can make an investment at cost[1] x>0. The cost is private information to the DSO. The DG and regulator only knows that the DSO's cost – to make it simple - is independent from DG's cost, and that it follows a probability distribution with density f(x) and cumulative probabilities F(x)=Prob{costs are less than equal to x}.

The aim of the DSO is to maximize expected revenue minus costs, i.e.

[1] Cost is here seen as the effective net real annuity of depreciation and capital cost in an efficient capital market as to avoid burdening the presentation with the consideration of the actual investment pattern, taxation and life cycle maintenance pattern.

$$E[R-I(R,x)x|x]$$

Here R is the revenue that the DSO is paid[2]. It may depend on its investments as well as any other possible verifiable information, including the DG investments. (We shall investigate the effects of asymmetric information not only about investments costs but also about who actually performs it in the final discussion). I(R.x) is the investment strategy of the DSO. It is defined by an indicator function with value one when investment[3] is undertaken and value zero otherwise. Lastly, we note that the expectation is a conditional one. It is the expected benefits given the private information about relevant investment costs.

2.3 DG

We model the DG in an analogous manner. The DG can make an investment at costs y>0. The cost is private information to the DG. The DSO and regulator only knows that the DG's cost – to make it simple - is independent from DSO's cost, and that it follows a probability distribution with density g(y) and cumulative probabilities G(y)=Prob{costs are less than equal to y}.

The objective of the DG is to maximize expected revenue minus costs, i.e.

$$E[S-J(S,y)y|y]$$

Here S is the revenue that the DG is paid. In case of a connection charge, S will be negative, and in case of net-benefits from installing the DG, say by the private benefit exceeding the installation costs, the net-costs y will be negative. Denote the binary investment strategy of the DG by the function J().

2.4 Symmetric cost distributions

To simplify the exposition and since we consider services that can be provided at either the DSO or the DG level – or which requires investments at both levels – we will assume that the distribution of the costs x and y are independent but identically distributed. That is f=g and F=G.

2.5 Substitutes or complements

As indicated, DG and DSO activities are sometime substitutes and sometimes complements. We shall model this by linking the investment decisions with the social value V generated.

The outcomes for complementary investments are listed in Table 2-1 below.

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[2] The actual reimbursement scheme for the DSO through allowed tariffs, recognized performance in yardstick regimes, separate by-pass of investment costs or socialized transfers from other gridlevels (transmission) is ignored here as only the behavioral effects are studied. Hence, we assume that the regulator enforces the same non-discriminatory financing pattern for this particular revenue as for any other DSO revenue, i.e. no additional distortion is introduced.

[3] The investment is assumed to be unique and indivisible, i.e. the investment decision cannot be fractional. The setting corresponds well to the first installation of a technology, but is less applicable to the sequential capacity reinforcement decision. The model can be extended to cover the latter type of decisions; we leave that for further work.

Table 2-1 Complementary investments.

	DG INVEST J=1	DG NOT INVEST J=0
DSO INVEST I=1	V	0
DSO NOT INVEST I=0	0	0

The outcomes for investment opportunities in substituting technologies are given in Table 2-2 below.

Table 2-2 Substitute investments.

	DG INVEST J=1	DG NOT INVEST J=0
DSO INVEST I=1	V	V
DSO NOT INVEST I=0	V	0

We see that in the case of complement investments, we require investments at both levels to produce the social value V. In case of substitutes, it suffices to have investments at one level – and there are no gains from simultaneous investments at both levels. In this paper, we focus on situations where the DSO and DG investments are substitutes.

2.6 Incentive compatibility

Since the DSO and the DG are independent parties, the regulator cannot rely on them to take socially optimal decisions unless they are privately motivated. Likewise, the DSO in a decentralized solution cannot rely on the DG to make the desired investments unless they are provided with private incentives. This is the so-called incentive compatibility property that any organization or regulation shall adhere to. Basically, we must respect that the investment strategies I and J are endogenous. They are chosen by the DSO and DG respectively, in strategies that are *compatible* with their assumed profit maximizing objectives.

For the DSO, this means that for all x

$$I(R,x) \in \mathrm{Argmax}_d\, E[R-dx|x]$$

That is, I(R,x) must maximize the expected profit given the private information about investments costs x.

Likewise, for the DG, we have for all y,

$$J(S,y) \in \mathrm{Argmax}_d\, E[S-dy|y]$$

2.7 Individual rationality

An additional condition can be imposed on any organization under voluntary participation: no one will accept a regulation where the expected net-benefits from new investments are negative, i.e.

$$E[R-I(R,x)x|x] \geq 0$$

$$E[S-I(R,y)y|y] \geq 0$$

2.8 First best solution

Before investigating the possible solutions under asymmetric information, we observe as a benchmark the so-called first-best solution. This is here defined as the solution when the regulator has perfect information about the costs of the DSO and DG, i.e., to invest if and only if (iff)

$$Min\{x,y\} \leq V$$

and in this case to implement the least costly investment level, i.e. if $x=Min\{x,y\} \leq V$, the DSO invests, $y=Min\{x,y\} \leq V$, the DG invests (in cases of ties the solution can be picked arbitrary).

The first best solution is illustrated in Figure 2-1 below. We see that investment takes place at the least costly level and that we only forgo investments in the red are where no level can make the investments at costs below the value V.

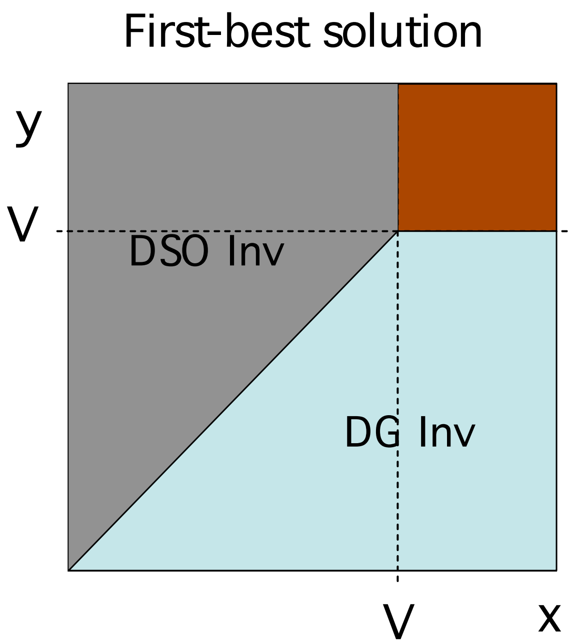

Figure 2-1 First-best solution

2.9 Next steps

We have hereby defined the setting in which the organizational forms and regulation shall work. We continue in the next chapter with a careful investigation of the case of substitute investments. The case of complementary investments is treated in an accompanying paper.

3 Integrated DSO and DG

If the DSO and DG are integrated, the regulator basically faces one entity[4] with some unknown costs z of making the investment.

An integrated DSO-DG will of course make the investment at the least costly level, i.e.

$$z=min\{x,y\}$$

with cumulative distribution

$$H(z) = Prob\{Z\leq z\} = 1-[1-F(z)][1-G(z)]$$

Since the regulator only knows H, not the specific z, his best strategy is to make a take-it or leave-it offer to the DSO-DG entity. This is a general result from mechanism design that has many applications, cf. e.g. Antle, Bogetoft and Stark (1999).

Let z* be regulator’s offer, the regulator’s expected value is

$$E(W) = [V-z^*]H(z^*)$$

Since the first factor is the net benefits when investments takes place and the supplier, the DSO-DG entity is paid z*, and the last factor is the probability that the DSO-DG actually implements the investment.

The first order condition for an optimal offer is therefore

$$z^* = V-[H(z^*)/h(z^*)]$$

We see that the regulator offers less than the value V. This reflects that he trade-offs the value to be gained from the costs of getting it. By increasing z*, the improvements are undertaken more often – but they are also more costly.

The solution with integrated DSO and DG activities is illustrated in Figure 3-1 below.

[4] The integration is here defined as the legal possibility for the DSO to undertake DG investments, including harvesting gains from sale of energy at competitive terms. However, since we are assuming (i) no non-grid related operation at the DSO, (ii) no downstream market power in the sale of energy for the DSO, the revenues resulting from the generation itself are normalized to zero as being competitively valued at marginal cost (excluding the grid impact that is explicitly modeled).

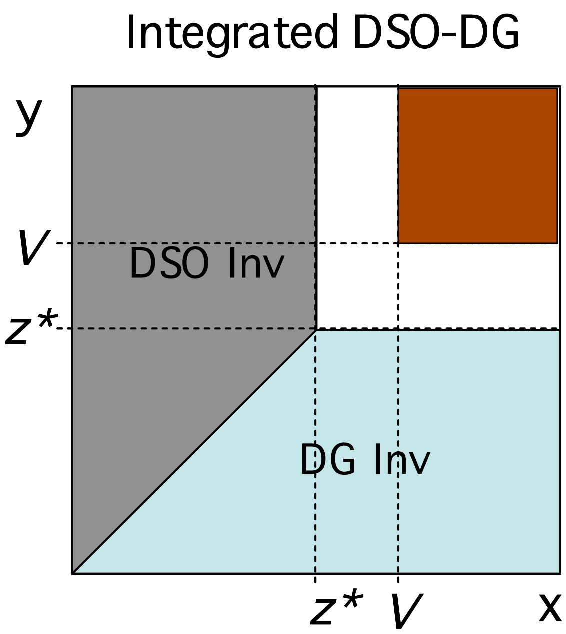

Figure 3-1 Integrated solution

We see that when investments do take place, they are implemented at the right level. The solution is attractive except that there are some social losses due to under-investments. In the white areas, the least cost alternative is less costly than the value, but nevertheless investments are rationed away. This underinvestment is a direct consequence of the mechanism to lower the information rents that the DSO-DG entity can earn.

Assuming for example that V=1 and that z follows a uniform distribution on [0,1], we get z* = 1-z*/1 or equivalently, z* =0.5. Hence, the regulator deliberately forgoes half of the attractive investments in order to get the other investments at lower costs. Put more generally, the desire to share the benefits with the consumers forces to regulator to forego some otherwise attractive investments at the DSO and DG levels.

As another example, let us assume that x and y are independent, uniformly distributed on [0,1]. The cumulative distribution of z=min{x,y} is therefore $1-(1-z)^2$ with density 2(1-z), such that the optimal z is given by

$$z = V - [1-(1-z)^2]/[2(1-z)]$$

For V=1 we now obtain z=0.354 as investment threshold level.

4 Separated DSO and DG under decentralized regulation

We assume next that the DSO and DG are vertically separated

Also, we assume that the regulation of the DG is delegated to the DSO. That is, the regulator incentivizes the DSO and the DSO can than decide whether to make the necessary investments or to outsource it to the DG. Before analyzing this case, we note that one can make the usual arguments for ownership unbundling (vertical separation), including the controllability of the DSO and the possibility to motivate it via relative performance evaluation (benchmarking) as it is the case in modern European regulation regimes based on revenue or price caps set partially by relative performance assessments such as frontier efficiency analyses.

In this case, the regulator can consider the DSO as the single contracting partner. Much like in the case of integrated ownership, the DSO can be characterized by its costs z of ensuring the new services with value V. In the present case, and given the separate ownership, however, the distribution of the DSOs direct or indirect cost z will reflect the internal incentive problem between the DSO and the DG. The DSO in its relation with the DG includes the same problems as the regulator does in its relation to the DSO.

The DSO can do the investment itself at a cost of x. Alternatively, it can try to outsource the investment to the DG level.

As before the optimal solution is found by backwards induction. Assume that the regulator has offered z*. Two situations can now be distinguished. In the first, the DSO has costs x above z* and must therefore rely on DG to do the investment. In the second, the DSO has costs x less than z* and can therefore make a profit by doing the necessary investments itself. Still, it may reduce costs by outsourcing if the DG has even lower costs. We shall now analyze these cases.

The first situation where x>z* is the simplest one. The DSO has only one possibility, namely to outsource. It offers DG a payment y* so as to solve

$$Max\ (z^*-y^*)G(y^*)$$

Or equivalently using again the first order characterization

$$y^* = z^*-[G(y^*)/g(y^*)]$$

That is, the DSO rations against the DG in same way as the regulator rations against the DSO or the integrated DSO-DG above. Let y*(z*) be the solution to this problem.

The second situation where x ≤ z* is one in which investment is certainly going to take place, but where the DSO can possibly improve its profit margin by the outsourcing.

Using y** as a threshold against the DG, the DSO solves

$$Max_{\ y^{**}}\ (z^*-x)[1-G(y^{**})]+(z^*-y^{**})[G(y^{**})]$$

To see this observe that with probability [1-G(y**)] the DG will decline the investment opportunity and the DSO will rely on its own investment. If, on the other hand, the DG undertakes an investment, which happens with probability G(y**), the DSO earns the margin between the regulator's compensation z* and its own compensation to the DG, y**. Let y**(x,z*) be a solution to the above problem.

The first order condition in this case is

$$y^{**} = x-[G(y^{**})/g(y^{**})]$$

In the case of y uniformly distributed on [0,1] and x≤2, we then have y** =x/2.

We can now summarize the DSO strategy. For x>z* it outsources using y*(z*) and the DG invests with probability G(y*(z*)). For x≤z*, there is always going to be investment, either in the DG when y ≤ y**(x,z*) or otherwise in the DSO.

From the point of view of the regulator, this means that choosing z* leads to DSO or DG investment with probability F(z*) + [1-F(z*)]G(y*(z*)).The regulator therefore chooses z* to solve

$$Max_{z^*}\ (V-z^*)[\ F(z^*)\ +\ [1-F(z^*)]G(y^*(z^*))]$$

The solution with decentralized contracting among vertical separated DSO and DG activities is illustrated in Figure 4-1 below.

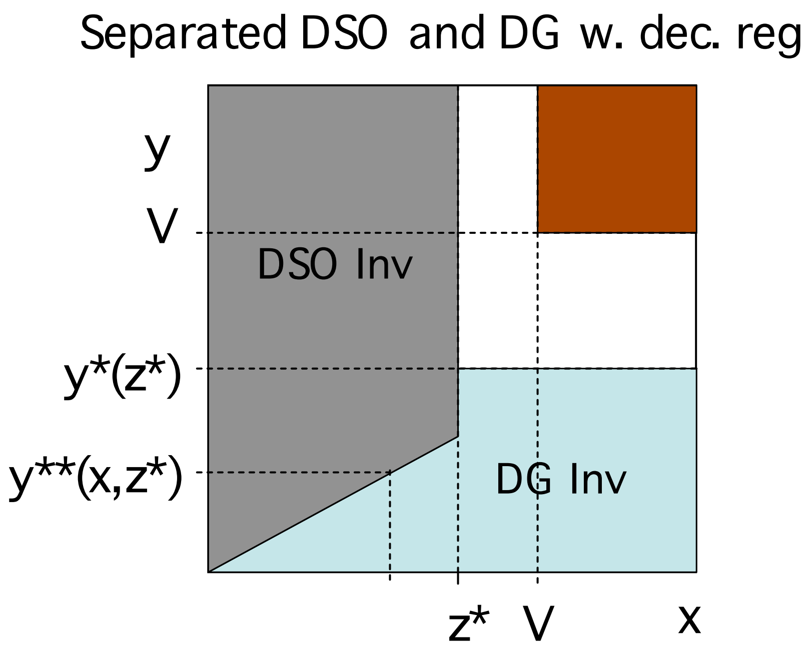

Figure 4-1 Separated DSO and DG w. decentralized regulation

We see that there is a general under investment as represented by the white area. Also, we see that the DSO tends to favor its own investments compared to DG investments. Again, this is a consequence of the rationing – in this case the DSO rations against possibly less costly DG solutions to save information rents to the DG level. Again, this represents a social loss.

Revisiting the previous example for uniformly distributed investment costs on [0,1], we get that y*(z)=z/2 and inserting this into the regulator's problem, we see that he will maximize (V-z)[z+(1-z)z/2]. For V=1, the corresponding first order condition is a second degree polynomial, and choosing the correct root (the left one) we get z=(8-sqrt(28))/6 = 0.4514.

This is a smaller target than the target, ½, that the regulator would use if only the DSO could provide the service. The intuition is that since the DSO has the possibility to outsource the investment, the probability distribution of the least cost alternative is having more mass on lower values than the uniform distribution. Indeed, if only the DSO can provide the service, the probability of acceptance using z is F(z) =z while with the DSO able to outsource also, the probability of acceptance is [F(z*) + [1-F(z*)]G(y*(z*))]= z+(1-z)z/2 taking into account the optimal response of the DSO in his outsourcing activities. The two situations are illustrated in Figure 4-2 below

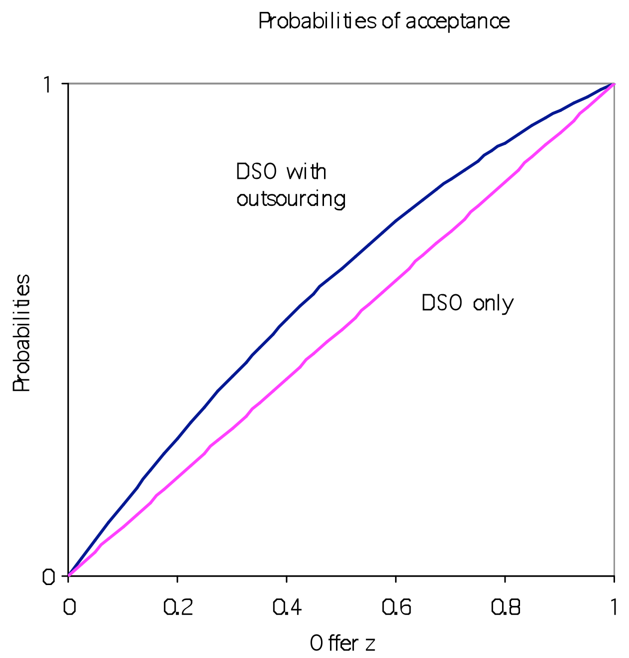

Figure 4-2 Impact on acceptance of outsourcing

This means that the regulator's trade-off between the probability of investment and price to pay is affected – it is now possible to lower the payment with less of an increase in the probability of forgoing investment.

5 Separated DSO and DG under centralized regulation

The last scenario we shall investigate involves separately owned DSO and DG that are directly contracted by the regulator in a centralized manner. There are two possible interpretations of this setting.

In the first, the regulator uses unconditional regulation in the sense that his regulation of the DSO is independent on the reaction that his regulation has on the DG and vice versa. This is the most obvious and probably the most natural regulation in a practical setting. It sends clear signals to the DSO and the DG.

The second interpretation involves conditional strategies. The regulator may use one of the parties as the default provider and the other as an optional provider. Thus, for example, the regulator could first invite the DG to do the investment and if it declines, it could turn to the DSO for possible investments. Clearly, the latter solution has some resemblances with the decentralized solution. Still, it will be different as we shall see since the regulator does not have the information about the DSO costs that the decentralized strategies made used of.

The *unconditional centralized solution* requires the regulator to choose costs targets x* and y* that the DSO and DG will get covered if they invest. The cost targets are set by the regulator to solve

$$Max_{x^*,y^*}\ (V-x^*)F(x^*)+(V-y^*)G(y^*)-V[F(x^*)G(y^*)]$$

To see this, observe that the regulator expected net benefit is the value V net of payment to the DSO if the DSO invests plus the net benefit from the DG's investments minus the value if they both invest (to balance out the double counting of values from the first two terms).

This problem leads to first order conditions

$$x^* = V[1-G(y^*)] - [F(x^*)/f(x^*)]$$

$$y^* = V[1-F(x^*)] - [G(y^*)/g(y^*)]$$

We see that the first order conditions have the same general structure as earlier. The regulator offers less than the possible value of the investment, i.e. he rations, to save information rents. In the present setting, the starting point is moreover not the value V but rather the discounted values V[1-G(y*)] and V[1-F(x*)] respectively, i.e. it is only the value V multiplied by the probability that the other level do not invest that counts. This reflects that the attainable value in this case since it is the value that is not already extracted by the other level. This leads to a more severe under-investment to lower the costs of double investments at low costs at both levels.

The solution is illustrated in Figure 5-1

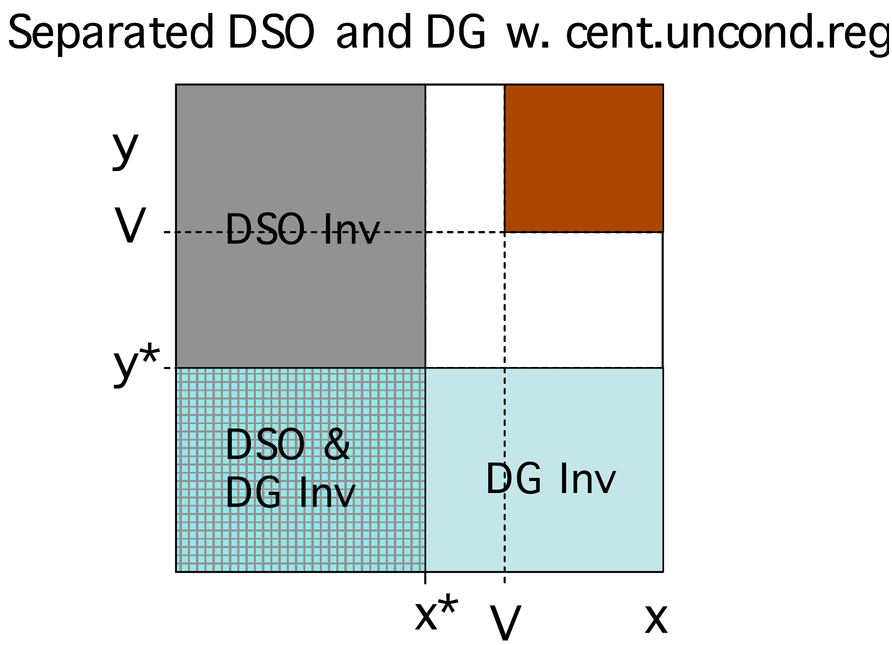

Figure 5-1 Centralized, unconditional regulation of DSO and DG

In the case of V=1 and uniform costs on [0,1], for example, we get x*=y*=1/3. Hence, the regulator rations more harshly against the DSO and DG (using 1/3 as opposed to 1/2 in the case of possible investment in one level only) to lower the cost of double investments. More generally, in the case of uniform costs on [0,1] and value V, the symmetric solution is

$$x^* = y^* = V/[2+V]$$

The regulator will always choose to ration - if only slightly for large values of V. This happens for the following reason: When the cost targets are getting closer to the upper limit 1, the marginal cost of rationing is declining since the forgone investments are most likely picked up by the other level. Also, the marginal benefits from rationing are increasing since the double investment problem is high when the cost targets are high and therefore the cost marginal saving in double investment costs is increasing for larger value of the targets. The cost targets are illustrated in Figure 5-2.

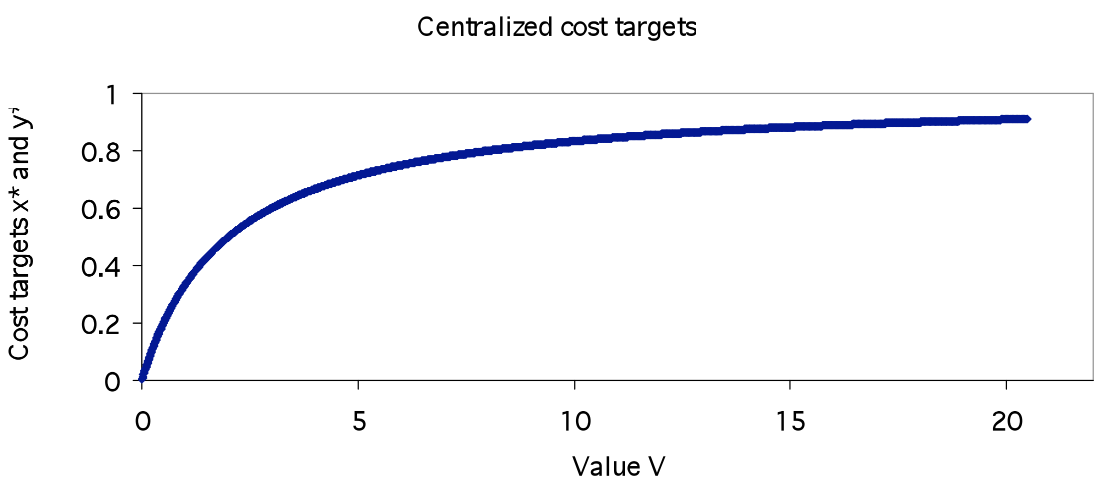

Figure 5-2 Targets in centralized, non-conditional regulation with uniform costs

Consider next the *conditional centralized solution.* Let us assume that the DG is the primary provider and that the DSO may be called upon to invest if the DG declines. The alternative situation with the DSO being the primary and the DG the secondary provider is similar. The conditional centralized solution requires the regulator to choose a cost target y* that is offered to the DG and cost target x* that is offered to the DSO if the DG has declined y*. These targets are set to solve

$$Max_{\,x^*,y^*}\ (V-y^*)G(y^*) + (V-x^*)F(x^*)[1-G(y^*)]$$

To see this, observe that the regulator expected net benefit is composed of two terms. The first is the value V net of payment to the DG y* if the DG invest. This happens with probability G(y*). The second term is the net benefit if the DG declines and the DSO accepts. This happens with probability [1-G(y*)]F(x*).

This problem leads to first order conditions

$$x^* = V - [F(x^*)/f(x^*)]$$

$$y^* = V-(V-x^*)F(x^*) - [G(y^*)/g(y^*)]$$

We see that the first order conditions have a structure quite similar to the previous problems. Indeed, the optimal cost threshold for the DSO, x*, is exactly as it would be if the DSO were the only possible provider. This is not surprising since the DSO in our setup is the secondary provider, i.e. x* is used when DG has already declined to do the investments. In setting x*, the regulator therefore faces the usual trade-off of lowering the price when investment takes place and at the same time running the risk of no investments. The second first order condition is also of the usual form, except that the value to be gained is lowered by the expected gains forgone by not using the DSO as the provider. That is, the value from having DG do the investment is reduced by the value of the option of using the DSO as the provider.

The solution is illustrated in Figure 5-3 below.

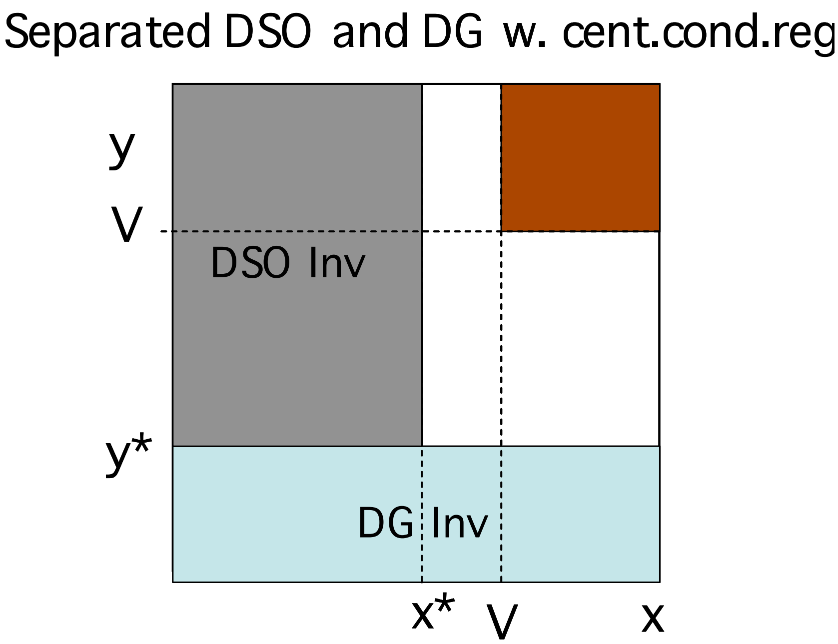

Figure 5-3 Conditional regulation with separated DSO and DG

In the case of cost uniformly distributed on [0,1] and value V (at the most 2), the optimal solutions are

$$x^* = V/2$$

$$y^* = (3/8)V$$

It may seem counter intuitive that we are willing to pay more for the DSO investment that for the identical DG investment. However, this is a consequence of the rent saving exercise. If the same opportunity is offered to both providers, the only role of the secondary provider would be to increase the investment probability. In the optimal solution, the secondary provider is also used as a competitor against the primary provider.

The conditional solution is always weakly superior to the unconditional solution. The see this, simply observe that the unconditional solution is also feasible in the conditional case – it is just not optimal. The disadvantage of the conditional approach from a practical perspective, however, is that it takes more time using a sequential two-stage approach rather than a simply single-stage approach. Also, this would make investment planning in the DSO more difficult since it cannot plan an investment based on its own cost alone –it must await the response of the DG.

The conditional approach can be refined into a series of conditional offer: First, DG gets an offer of a relatively low cost target. If DG declines, the DSO gets an offer of a slightly higher cost target. If it declines, a new and higher offer is made to the DG and so on. Such *sequential or parallel bargaining* can lower the rents to the DG and DSO levels, but it would run into more serious practical problems of time needed and investment planning as discussed above. For this reason, we shall not expand on it.

6 Conclusions

In this paper, we have investigated how the organization and regulation of substitute DSO and DG investments affect the amount of resulting investments and the allocation hereof among the DSO and DG levels.

To illustrate our findings, one may consider the outcomes in a context with independent uniform DG and DSO costs on [0,1] and a total consumer value of the investment of V=1. We have included small illustrations along these lines in each of the chapters, and based hereon it is relatively straightforward to develop Table 6-1 below.

Table 6-1 Illustrations of the different scenarios

Setting	Optimal targets	Optimal strategy	Prob {Inv}	Ration-ing	Misallo-cation	Double invest
First best	$z^* = \text{Min}\{x,y\} =$	1.000	1.000	No	No	No
Integrated	$z^* = \text{Min}\{x,y\} =$	0.354	0.583	Yes	No	No
Separated and dec reg	$z^* =$ &$(y^*(z)= z^*/2)$	0.451	0.575	Yes	Yes	No
Separated and centr reg	$x^* = y^* =$	0.333	0.556	Yes	No	Yes
Separated and cond centr reg	$y^*= 3/8,\ x^* = 1/2$	3/8 and 1/2	0.688	yes	Yes	No

We see that the best outcome is when the two levels are integrated. In this case, there will be no misallocation of investments, i.e. the cheapest level will be the one investing (if any) and there will be no useless double investments. There is still losses associated with the outcome, namely due to the rationing. Rationing in the sense that not all investments with cost below the value to the consumers are undertaken is part of the solution since it enable the regulator acting as a substitute consumer to lower the information rents he has to pay.

If – for reasons that may go beyond the scope of the model – the two levels are separated (unbundled), we can foresee two possible organizations of the regulation. In the first, the regulator contracts with the DSO that has the option to outsource the investments. In the other, the DSO and DG are contracted individually by the regulator.

The best separated outcome is the first one, i.e. it involves decentralized regulation: only the DSO is contracted directly and the possible regulation of DG is delegated to the DSO. The advantage of this approach of having decentralized regulation of DG is that the DSO has private information about its own costs and that it can use this information when deciding how to incentivize DG. Nevertheless, this setting leads to less overall investment – at a higher cost to the consumers. Two types of inefficiencies are present, namely rationing and some misallocation of investment among the two levels. The DSO favors its own investments since outsourcing generates costs of asymmetric information.

When the regulator contracts directly with both levels, the outcome is less efficient – there will be rationing and double investments, i.e. in some cases, the DG and DSO levels will both end up investing even though this is unattractive since the investments are substitutes. This can be partly circumvented if the regulator uses conditional regulation such that the offer to one level depends on the response of the other level. The latter however may be a difficult approach in practice since it requires time to first offer the investment to a primary provider and next to a secondary provider if the primary provider declines.

In short, therefore, from the point of view of substitute investments, the regulator will prefer an integration of the DSO and DG activities – and if this is not possible, it would prefer a regulation of one of the levels leaving the control of the other to the directly regulated level.

Of course, this ranking of the different organizational and regulatory solutions may conflict with other objectives that we have ignored, including the need to incentivize cost reductions at the DSO level in general via relative performance evaluations like in a high powered revenue cap (CPI-X) regulation. Taking the broader perspective, our results show that one should at least include DG activities – or the accommodation hereof – in the service description of the DSO. The latter confirms ongoing work by the German regulator, BNA.

Let us close by noting that we could have used alternative objectives for the regulator. We could for example say that information rents are simply a wealth transfer and hence that it is not costly – or at least only costly in terms of the possible tax distortions created by the collection of funds to cover the rents. In such a situation, we would get related results except that the rationing in this paper will be at a lesser scale.

Also, we could have extended the analysis by working with imperfect monitoring of the investments. If the information system cannot identify investments with probability one but if there is an information system that gives some information about the likelihood that investments took place, we would get similar results – but we would have to rely on reimbursements that depended on the information system, e.g. high revenue caps in case of a good signals and lower reimbursement levels in case of bad news. The analysis of such situations could follow the analyses initiated in Bogetoft and Olesen (2003,2004)

7 References

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