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EWI Working Paper, No 13/12

June 2013

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ISSN: 1862-3808

Investment Coordination in Network Industries: The case of electricity grid and electricity generation

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June 12, 2013

Abstract

Liberalization of network industries frequently separates the network from the other parts of the industry. This is important in particular for the electricity industry where private firms invest into generation facilities, while network investments usually are controlled by regulators. We discuss two regulatory regimes. First, the regulator can only decide on the network extension. Second, she can additionally use a "capacity market" with payments contingent on private generation investment. For the first case, we find that even absent asymmetric information, a lack of regulatory commitment can cause inefficiently high or inefficiently low investments. For the second case, we develop a standard handicap auction which implements the first best under asymmetric information, if there are no shadow costs of public funds. With shadow costs, no simple mechanism can implement the second best outcome.

Key Words: Regulation, commitment, capacity markets, transmission system investment

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JEL Classification: D44, D47, K23, L51, L94

1 Introduction

In many network industries like rail, gas or electricity, liberalization has led to an "unbundling" of the network as the monopolistic bottleneck from the potentially competitive parts. The rationale for separating the network is to avoid that a vertically integrated firm can use the network access to discriminate against potential downstream competitors. This vertical separation has introduced a new problem, namely, how to coordinate the network investment with investments in the competitive parts.

This coordination problem is particularly pronounced in the electricity industry. In an early review article on electricity market liberalization, Joskow noted:

> The key technical challenge is to expand decentralized competition in the supply of generation in a way that preserves the operating and investment efficiencies that are associated with vertical ... integration ... (Joskow, 1997, 127)

Investment coordination becomes increasingly relevant in countries that restructure their industries towards a larger share of renewable electricity generation. For instance, in the UK, there are technically productive off-shore wind opportunities available in Scotland; however, since the load center is in the South, this requires large North-South network extensions. These could be reduced if less productive locations in the South would be used. In Germany, the same regional pattern holds for renewables. At the same time, new fossil capacities are required in the South of Germany to compensate for the accelerated decommissioning of nuclear power. However, at least for hard coal fired power plants costs are lower in the North than in the South (due to lower transport cost).[1] Again, private generation investors would prefer Northern locations, which would require an extension of the North-South network connections.

While in liberalized electricity industries investments in generation capacity are usually decided by private firms, large network extensions are based on regulatory decisions. In Europe, investors typically apply for so-called investment budgets. These investment

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[1] Different input costs of coal plays an important role in many countries. For instance in the US, cost of coal delivered for electricity generation can differ by more than the factor two, see e.g. Table 4.10.A, US Energy Information Administration / Electric Power Monthly June 2012.

budgets are subject to regulatory approval, and, if approved, are financed by increasing the (regulated) network charges.[2] Although private firms decide on investments in generation, the fear of insufficient investment incentives (due to a "missing money problem") has led many countries to discuss the introduction of capacity markets, i.e., a mechanism where the regulator grants payments to private firms in order to stimulate investments into generation capacity. Such a mechanism might well affect not only the size but also the location of generation investments.

We are therefore interested in the question how to coordinate network extensions with generation investments, without and with a capacity market. In the absence of a capacity market, a welfare maximizing regulator who can decide only on network extensions typically faces two challenges. First, a lack of regulatory commitment. The regulator might want to long-term commit to undertake certain extensions (or she might want to commit not to extend certain network connections), but she might be unable to do so. Second, the regulator might face an asymmetric information problem, e.g., she might not know the cost of generators. If a capacity market is installed, commitment might less be a problem, since the regulator simultaneously can decide on the network extension and the capacity market design. However, asymmetric information and the cost of public funds (in particular for payments to private firms for investing in capacity) will be important.

To analyze these issues we use a simple network model with two nodes, North and South. Demand is stochastic at each node, but on average lower in the North than in the South. Without additional investment, there is the danger of undersupply in the South, which can be mitigated linking the two nodes, or it can be avoided by installing one additional unit of generation in the South, or by installing one additional unit in the North and linking the two nodes (it will never happen that more than one unit is added). Private firms decide on generation capacity investments, the government decides on building the link or not. For the sequence of moves, we interpret the outcome in which the regulator moves second (first) as the "no commitment" ("commitment")

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[2] For instance, in the German energy regulation, an "investment budget" increases the so-called "long-term unavoidable cost" and thereby increases the revenue cap of the firm (see "Anreizregulierungsverordnung, § 11 (2) no. 6"). For the UK, see the regulator's decision to accept an investment budget equivalent to almost half of the network's book value of assets (4.5 bn. Euro) for the period 2008-2012 (Ofgem, Transmission Access Review, Ref. 175/08, p. 5 and p.8).

outcome.

Without a capacity market, even with a fully informed regulator, two types of inefficiencies can occur with "no commitment". First, an "investment forcing" inefficiency, where private investors invest in the North, to which the regulator's best response is to hook up the North with the South, since otherwise the South faces the danger of a shortage. Investing in generation and network may be inefficient but preferred by the private firms if the investment in the North is cheap, while the link is expensive. The reason is that the private investor does not have to bear the network costs caused by his locational choice. Second, there might be a network "investment preempting" inefficiency. Investment in the South might be very profitable, but building the link only might be welfare superior (e.g., if the link is very inexpensive). The regulator would like to commit to building the link, but once the private investor invested in the South, adding a link is useless, since the additional generation capacity will not be needed in the North. Both inefficiencies vanish if the regulator moves first, i.e., commitment solves these sorts of opportunistic behavior problems.

If the costs of the firms are private information, this no longer holds. Moving second can become preferable to the regulator, in particular, if the asymmetric information problem is very severe. The reason is that from the informed firms' investment decision, the regulator can learn something about the state of the world. Commitment would require committing to disregard this additional information. This reflects a trade-off between the aim to avoid opportunistic behavior (which calls for moving first) and the aim to elicit information (which calls for moving second).[3]

If the regulator can also directly affect the private firms' investment decisions, the regulator can use a specific form of a capacity market to implement the first best if there are no shadow costs of public funds. She can do so by using a standard auction with a reserve price and a "handicap" (or "malus"). The reserve price determines the amount of capacity to be built, while the handicap steers the generation towards the right location. The handicap depends on where the investor wants to build (North or South), and is added to the respective bids. It is tailored such that it internalizes the externalities the private bidders inflict on the regulator, thereby solving the invest-

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[3] We also discuss "full commitment", i.e., the regulator can ex-ante commit to condition the network decision on the observed private investment decision. This does not qualitatively change the results.

ment forcing inefficiency. The right choice of the reserve price solves the investment preempting inefficiency.

If there are shadow costs of public funds, the first best can no longer be implemented. We find that there will be a distortion towards less investment into generation capacity. If there is investment, the decision where to invest is distorted, too. No simple capacity market exists to implement the second best outcome.

That a lack of regulatory commitment can severely affect infrastructure industries is widely acknowledged in the literature. Levy and Spiller (1994) looked at the telecommunications industry and argued that the threat of ex post expropriation of private investors might make public ownership of telecommunications firms superior to private ownership. Various papers investigated the topic further for various utility industries (Troesken (1997) for gas, Troesken (2003) and Masten (2011) for water). Our paper complements this strand of literature by analyzing a hybrid industry structure between the two extremes of public and private ownership of an integrated firm: We look at an "unbundled" industry, and we focus on the problems arising from the necessary coordination of the public and the private sector. In addition, we point to possible limitations of long-term commitment in the case asymmetric information.

Albeit its importance for regulatory practice, and although the underlying problem is essentially a (hold-up) problem of coordinating complementary investments, there is little literature that directly tackles our research question. The literature on network investment and the (non-) desirability of merchant transmission investment (Chao and Peck (1996), Bushnell and Stoft (1996), Joskow and Tirole (2005)) usually takes the generation capacity as given.[4] The literature on the (non-) desirability of generation capacity markets (Hogan (2005), Cramton and Stoft (2005), Cramton and Stoft (2006), Joskow (2008)) usually takes the transmission network as given.[5]

A few papers take up the issue of coordination of generation and network investments

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[4] Joskow and Tirole (2005), p. 249-250, however, briefly discuss a possible interaction in form a "preemption" of private network investments by first-moving generation investors. This is similar to our investment preempting effect.

[5] Some capacity market designs explicitly account for the fact that capacity markets might need a regional dimension to account for network congestion, see e.g. the "Locational Deliverability Areas" in PJMs capacity auctions (PJM, 2015/2016 RPM Base Residual Auction Results, p. 2). However, this regional component of the generation auction is not explicitly linked to investments into transmission capacity (but only to the existing transmission system).

and discuss it in a framework related to ours. Sauma and Oren (2006) investigate a three stage game where first a benevolent regulator decides on network extensions, then private firms decide on generation investments, and in the last stage there is oligopolistic competition. They compare a "pro-active" regulator to a "passive" regulator, where the former optimizes by anticipating the private firms' reactions to the network decisions, while the latter takes the private investment decisions as given. However, there is no asymmetric information in the model by Sauma and Oren (2006). Hence, their "passive" regulator always does worse in welfare terms by construction, while in our model we show that lacking commitment can be beneficial if the asymmetry of information is large. Rious, Perez, and Glachant (2011) take up the idea of a passive and a pro-active regulator. They focus on the issue of timing, pointing out that usually network extension need more time than power plant investments. They therefore ask whether the network-investor should move first, i.e., build the network before the power plant is finished. Being "pro-active" in this sense might be suboptimal if it is not certain that an announced power plant is actually realized. Although this model introduces some form of uncertainty on the side of the regulator, in their model generators do not behave strategically, while one of the research interests in our approach is to investigate opportunistic behavior of the private investors. In Sauma and Oren (2009) the authors change the focus and investigate the investment incentives that private firms, which are also active as generators, might have to invest in network extensions. In this article, they also analyze the effect on investment incentives that are created if generators are equipped with financial transmission rights in case they invest into transmission, or not. Here the main difference to our approach is that we restrict attention to network decisions that are taken by the regulator, while expanding the analysis by also looking at generation investments.

To summarize, our contribution is to (i) combine the analysis of generation and network investment, to (ii) do so in a framework where the regulator can decide on the network expansion, with or without the ability to provide incentives for investments into generation, and by (iii) explicitly taking into account asymmetric information problems and commitment problems on the side of the regulator.

The remainder of the paper is organized as follows. Section two introduces the model. Section three analyzes the case where only the network is regulated. Section four deals with the option to use a capacity market. Section five concludes.

2 The Model

There exist two locations, North and South. Demand in the North is $D_N \in \{0, 1\}$, where $D_N = 1$ occurs with probability q_N, and $D_N = 0$ with probability $(1 - q_N)$. Demand in the South is larger, $D_S \in \{1, 2\}$, where $D_S = 2$ occurs with probability q_S, and $D_S = 1$ with probability $(1 - q_S)$. At each location, there is capacity of size one installed, with marginal cost of production of zero. One unit of generation capacity can be added in the North at cost c_N and in the South at cost c_S. The cost c_N (c_S) are drawn from some distribution F_N (F_S) with densities f_N (f_S). Both locations can be linked together at cost L.

We use a reduced form to simplify the analysis of the electricity markets. Prices in each region are zero in case of excess supply, they equal $m > 0$ if demand equals supply, and they equal $M > m$ if demand exceeds supply. In the latter case, black out cost to society of $B \geq m$ occur. This last assumption implies that the market faces a "missing money problem" since, if new capacity is added, the price for generation will always be below the value of lost load, B, and therefore private incentives to invest can fall short of the social incentives to do so. We assume that the electricity market is sufficiently competitive that all capacity is always offered. Hence, inefficiencies can not arise from strategic firm behavior in the electricity market. Furthermore, there is free entry, i.e., any profitable capacity will be added in the market. If there are two alternative opportunities to enter, firms will choose the more profitable one. Firms maximize expected profits. For our analysis the identity of the firm building the additional generation capacity does not matter. It could be an incumbent firm already operating one of the two generation units, or it could be an entrant.[6] The government maximizes expected welfare by minimizing the expected losses from outage and the cost of investments. L is borne by the regulator, or ultimately by the consumers by higher network fees that

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[6] At most one unit of generation capacity will be added since otherwise supply always exceeds demand and the price will always be zero.

increase electricity prices.

For the first best solution, consider the case that the realization of capacity cost is such that $c_N < c_S$. Three cases matter. (i) Either a social planner would add one unit of generation capacity in the South, we call this the outcome $\mathcal{S}$; (ii) or just build a link (network connection at cost L), outcome $\mathcal{L}$; (iii) or would build a generation unit in the North and the link, outcome $\mathcal{NL}$.

We assume that the status quo $\varnothing$ is welfare inferior to any other alternative, i.e., it is never optimal to implement doing nothing. Building only in the South is welfare maximizing if it is better than building only the link

$$W_S > W_L \Leftrightarrow c_S < q_S q_N B + L, \tag{1}$$

and better than building capacity in the North and linking the North:

$$W_S > W_{NL} \Leftrightarrow c_S - c_N < L. \tag{2}$$

Building the link only is welfare maximizing if this will be better than additionally adding also a generation unit in the North

$$W_L > W_{NL} \Leftrightarrow c_N > q_S q_N B, \tag{3}$$

and if (1) is violated. Building in the North and adding the link is optimal if (2) and (3) are violated. To ensure that the status quo is welfare inferior to all other alternatives, we assume $q_S B \geq \max\{c_S, L + q_S q_N B, c_N + L\}$.[7]

3 Regulating the network only

In this section we confine the regulatory intervention to decisions on the network extension. The regulator decides on building the network as a public investment (in this section we abstract from shadow costs of public funds), but does not interfere directly

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[7] If $c_S < c_N$, only the alternatives $\mathcal{S}$ or $\mathcal{L}$ would be optimal, depending on whether condition (1) is satisfied or not.

into the decision of the private firms on building generation capacity. We analyze the effect of different levels of information available to the regulator, as well as differences in the regulator's ability to commit to investment decisions. We interpret the sequence of moves where the regulator moves first as "commitment", and we refer to the sequence of moves where the regulator moves second as "no commitment".[8]

3.1 Fully informed regulator

Symmetric information and commitment: Assume that the regulator knows the realizations of the cost parameters c_S, c_N, and L, and we maintain the assumption that $c_S > c_N$. In this case, inefficient outcomes can result only from the fact that the private benefits of generation investments (m) fall short of the social benefit of avoided black out costs (B). This happens, (i) if it would be efficient to implement $\mathcal{S}$, but $q_S m < c_S$, or (ii) if it would be optimal to implement $\mathcal{NL}$, but $q_S q_N m < c_N$. Both inefficiencies reflect in a reduced form a "missing money problem".

Symmetric information and no commitment: A lack of regulatory commitment introduces additional inefficiencies which are not caused by the missing money problem. If the regulator moves second, we find the following:

Proposition 1 *With full information, but without commitment, the first best allocation can not always be implemented, even in the absence of a missing money problem. There can be either too much or too little investment.*

Two kinds of inefficiencies are possible. First, imagine that it is optimal to have generation investment in the South, $\mathcal{S}$. This applies if the cost difference at the two locations is small compared to the cost of the link, $c_S - c_N < L$. However, if the government can not commit not to build the link, it can be more profitable for the firms to locate the additional generation unit in the North, relying on the fact that the government will then respond by building the link to avoid a shortage in the South.

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[8] One might argue that identifying "commitment" with moving first in this game is not fully adequate. Rather, "full commitment" would be a situation in which the regulator moves second, but can ex ante commit how to react to the firms' decisions. We discuss this in the Appendix and show that the regulator can gain very little from this additional commitment power.

This is the case if

$$q_S m\left(1-q_N\right) < c_S - c_N < L, \tag{4}$$

which requires that

$$L - q_S m\left(1-q_N\right) > 0. \tag{5}$$

The term on the left hand side of (5) is the excessive private incentive to invest in the North, compared to investing in the South. If it is positive, the private profit gains from switching to building in the South (which are $q_S m\left(1-q_N\right)-\left(c_S-c_N\right)$) fall short off the social gains, i.e., the reduction in social cost of doing this (which are $L-\left(c_S-c_N\right)$). It implies that there is the possibility of free-riding by the private investors with respect to the cost of building the network, L, which are triggered by the private decision to build in the North, but are not borne by the private investors. As a consequence, there is a welfare loss even in the absence of the "missing money problem", i.e., even if $c_S < q_s m$ and if S would be optimal. We call this the *investment forcing effect,* since the firms can force the regulator to invest into the network to avoid ex post inefficiencies, although the investment in building the link is not ex ante efficient.

The second inefficiency is due to underinvestment in the network. This happens if the inequalities in (4) are reversed. Imagine that in the first best the capacity should be built in the North and the link should be build, $\mathcal{NL}$. This happens if the link is cheap compared to the cost differential for capacity between the two locations, $L < c_S - c_N$. Assume further that expected profits in the South are large, i.e., $q_S m - c_S > q_S q_N m - c_N$. Then, if $q_S m\left(1-q_N\right) > c_S - c_N > L$, implying that $\mathcal{NL}$ is optimal, firms would nevertheless build generation capacity in the South, and given this, the regulator's best response obviously is not to build the link (since the link never makes sense if capacity is added in the South). We call this latter effect the *investment preempting effect.*

If the regulator were to move first in the game she could solve either problem. If she faces the *investment preempting effect*, she needs to long-term commit to building the link, i.e. she commits to building the link independent of what the firms do. If she is confronted with the *investment forcing effect*, she needs to do the opposite, i.e., to commit never to build the link, even if the firms were to build in the North. Therefore, commitment is valuable to the regulator.

Proposition 2 *With full information, commitment is welfare superior to no commitment. Absent a missing money problem, i.e., if $B = m$, commitment implements the efficient outcome.*

Proof. For the first statement: With regard to the optimal outcome, three cases are possible. (i) In the first case, the efficient outcome is $\mathcal{S}$. If $q_S m - c_S \geq 0$, then with commitment the regulator implements $\mathcal{S}$ by not building the link (*never*). However, without commitment, and $q_S q_N m - c_N \geq q_S m - c_S \geq 0$, the regulator cannot implement the desired outcome $\mathcal{S}$. If $q_S m - c_S < 0$, neither with commitment nor without commitment, $\mathcal{S}$ can be implemented; in either case the regulator implements $\mathcal{L}$ as the second best solution. (ii) The second case is where the efficient outcome is $\mathcal{NL}$. Then, there is no difference between commitment and no commitment, except for the case where $q_S q_N m - c_N < q_S m - c_S$, where commitment by *always* building the link still implements $\mathcal{NL}$, while absent commitment, S is implemented. (iii) In the third case, the efficient outcome is $\mathcal{L}$. Then, commitment and choosing *always* implements $\mathcal{L}$ (note that $\mathcal{L} \succ \mathcal{NL} \rightarrow q_S q_N m - c_N < 0$), while if $q_S m \geq c_S > q_S q_N B + L$, which may hold for q_N and L sufficiently small, no commitment leads to $\mathcal{S}$ instead of the efficient $\mathcal{L}$.
For the second statement: With commitment, under (i), an inefficiency can arise only if due to $q_S m - c_S < 0$, *never* would implement the status quo $\varnothing$, while $\mathcal{S} \succ \varnothing$; but absent a missing money problem $q_S m - c_S < 0$ implies $\varnothing \succ \mathcal{S}$. Similar under (ii), an inefficiency can arise only if *always* implements $\mathcal{L}$, since $q_S q_N m - c_N < 0$, while $\mathcal{NL} \succ \mathcal{L}$; but absent a missing money problem $q_S q_N m - c_N < 0$ implies $\mathcal{L} \succ \mathcal{NL}$. Finally, under (iii), commitment always implements the efficient outcome. ■

The lack of regulatory commitment discussed in this section causes efficiency problems which are the result of missing coordination of the two types of investments, generation and network. Missing coordination is due to the vertical structure, namely vertical separation and regulated network investment. One might ask whether alternative vertical arrangements might do better. One obvious alternative is to consider vertical integration, where an integrated firm decides on generation and network investment. Another alternative is to allow for "merchant transmission investments", i.e., building of the network by an independent private third party which can charge for transmission. We discuss both alternatives in more detail in the Appendix and show that (i) both may contribute to reduce the *investment forcing effect,* but (ii) both also introduce additional inefficiencies.

Obviously, a vertically integrated firm cannot be "forced" to invest in the network by generation investments it undertakes itself. However, a vertically integrated firm will use its network decision strategically to prevent the threat of market entry by other firms who need the network to build additional generation in the North. Thus, vertical integration leads to too little network investment in order to foreclose the market.[9]

Also a merchant transmission investment set-up can be used to reduce the *investment forcing effect*: if the network is not profitable for the merchant, he will not build it, even if this would ex post (after the generation investment in the North is taken) increase efficiency. Delegating the network decision to the merchant is then an instrument to overcome the regulator's commitment problem. However, the merchant introduces other efficiency problems, for exactly the same reason. The merchant does not care whether the network increases efficiency, but will only build it if this is profitable for him; thus, there will be underinvestment in the network.

To summarize, the alternative institutional set-ups can perform better if the *investment forcing effect* is severe; if it is not present, they are welfare inferior to the regulated network decision discussed in this section.

3.2 Firms' costs are private information

Consider the case that the regulator is uncertain about the firms' investment costs, while firms know their costs. It is not surprising that with asymmetric information even a regulator with commitment power is unable to implement the first best. Even worse, commitment in the sense of moving first, might no longer be valuable to the regulator.

To illustrate these effects of asymmetric information, consider the following simple example. Assume that the only value unknown to the regulator is c_N. All other values are common knowledge, and give by:

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[9] Such types of foreclosure effects are well established in the literature, see e.g. Leautier and Thelen (2009), p. 133.

c_S	L	q_S	q_N	m	B
1150	600	0.7	0.7	2400	4000

c_N is uniformly distributed between 400 and 600, and its realization is known only to the firms, not to the regulator. The expected cost of $\mathcal{NL}$ are 1100, while the cost of $\mathcal{S}$ equal 1150, and the cost of $\mathcal{L}$ are even higher (2560). Thus, the regulator wants to implement $\mathcal{NL}$ and can do so (given commitment power) by moving first and building the link.[10] However, if it turns out that c_N is very large, e.g. $c_N = 600$, then ex post it would be optimal to have implemented $\mathcal{S}$ (since the cost of $\mathcal{NL}$ actually equal 1200). However, the regulator can not hope for truthful revelation of the realization of c_N from the firms, since firm profits in case of $\mathcal{NL}$ are higher than under $\mathcal{S}$, even at the high level of c_N (576 compared to 530). This is just another application of the *investment forcing effect.*[11]

Moving first does not only fail to implement the first best under asymmetric information; it might even become worse than moving second, in particular if the problem of asymmetry of information becomes more severe. To illustrate this, let the variance of the distribution of c_N rise, such that c_N is distributed uniformly between 0 and 1000. Since the investment in the South is always privately profitable, the regulator who moves first and does not build the link (*never* builds the link), knows that costs will be 1150. If she moves first and builds the link (*always* builds the link), she can rely on private investment in the North and expected costs are therefore still 1100 in this case. However, if she moves second, firms will invest in the North only of this is more profitable than investing in the South. This is the case only if c_N is sufficiently small: $c_N < q_S q_N m - (q_S m - c_S) := Z$, i.e., $c_N < 646$ in the numerical example. Therefore,

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[10] Even with the highest realization of c_N, building in the North is still profitable, therefore, the regulator need not fear ending up with outcome $\mathcal{L}$.

[11] Recall that we restrict the regulator to an investment decision in this section. Thus, the regulator cannot punish the firms ex post for reporting incorrect information, or information that turns out to be inconsistent with the firms' investment decision. The next section solves the regulator's problem for the case where the regulator can offer more general contracts.

expected costs of moving second (*nocom*) equal

$$\begin{aligned} C_{nocom} &= prob\left(c_N \leq Z\right) \cdot \left(E\left[c_N | c_N \leq Z\right] + L\right) + \left(1 - prob\left(c_N \leq Z\right)\right) \cdot c_S \\ &= 0.646 \cdot (323 + 600) + 0.354 \cdot 1150 \\ &= 1003. \end{aligned}$$

Moving second therefore leads to lower expected cost to the regulator.

Proposition 3 *If costs are unknown to the regulator, no commitment can be welfare superior compared to commitment.*

The reason for this is simple: Moving second reveals valuable information to the regulator. She can learn something from the firm's decision where to build.

In this example, the revelation of information is more valuable to the regulator than the ability to counteract the firms' opportunistic behavior. This, obviously, need not always be the case. But with increasing uncertainty, the latter loses importance compared to the former.

Figure 1 illustrates this on a more general level for the case that only c_N is unknown to the regulator. In the upper part, the horizontal arrows indicate the outcome that is implemented as a function of the realization of c_N for the different cases of commitment power. In the lower part, the first best outcomes are given; in the lower line for the case that there is an excessive private incentive to switch from $\mathcal{S}$ to $\mathcal{NL}$, i.e., (5) holds, or vice versa for the upper line (in the numerical example, we were in the lower case, since there $q_S q_N m - (q_S m - c_S) = 646 > 550 = c_S - L$).

The area 1 in Figure 1 reflects the *investment preempting* inefficiency: For these realizations of c_N, no commitment implements the wrong outcome $\mathcal{S}$. If there is a lot of probability mass on region 1, then committing *always* to build the link is valuable for the regulator. Vice versa for region 2: if a lot of probability mass is on region 2, it is valuable to commit *never* to build the link, because this avoids the *investment forcing* effect.

However, as with increasing variance more probability mass tends to be shifted to the right of region 1 and at the same time to the left of region 2 (e.g., with a uniform distribution, or a normal distribution, as the variance goes to infinity, while holding the mean constant), the relevance of avoiding these two effects decreases. At the same time, the problems of commitment become more severe. With increasing variance, realizations to the left of region 2 become possible (or tend to be more likely), for which *nocom* is superior to *never*. If the regulator moves first, she might try to avoid this by *always* building the link. But then, with high variance, she increasingly runs the danger of ending up implementing $\mathcal{L}$, since very high realizations of c_N become more relevant. And if $\mathcal{L}$ is inferior to $\mathcal{S}$ (for instance, because B is very large), *nocom* will dominate both commitment alternatives, *always* and *never*.

This reasoning reveals a general trade-off involved when deciding whether to commit to a certain regulatory strategy or not. A lack of commitment increases on the one hand the danger of opportunistic behavior of the regulated firm. In our example, the opportunistic behavior stems from the *investment forcing effect* and the *investment preempting effect*. On the other hand, commitment has a cost in an uncertain environment. Commitment can require to disregard relevant future information that is revealed by choices of better informed agents. In our example, a regulator who does not commit can use additional information that firms reveal by their locational choice on the cost level. Therefore, if uncertainty becomes very large, being able to incorporate the additional information becomes very valuable, hence the regulator would prefer not to commit.

4 Introducing a (generation) capacity market

In this section we assume that the regulator does not only decide on building the link, but can also influence the firms' investment decision by payment schemes. One way to do so would be to introduce a capacity market which several countries have done (e.g., in the US in New England or in PJM), or are planning to do (in the UK). In a capacity market, the regulator pays firms to invest into generation capacity. The main focus of such capacity markets is to avoid the negative consequences of the missing money problem, i.e. to prevent underinvestment in generation capacity. Our analysis will show that a capacity market has to be coordinated with investments into the network in a

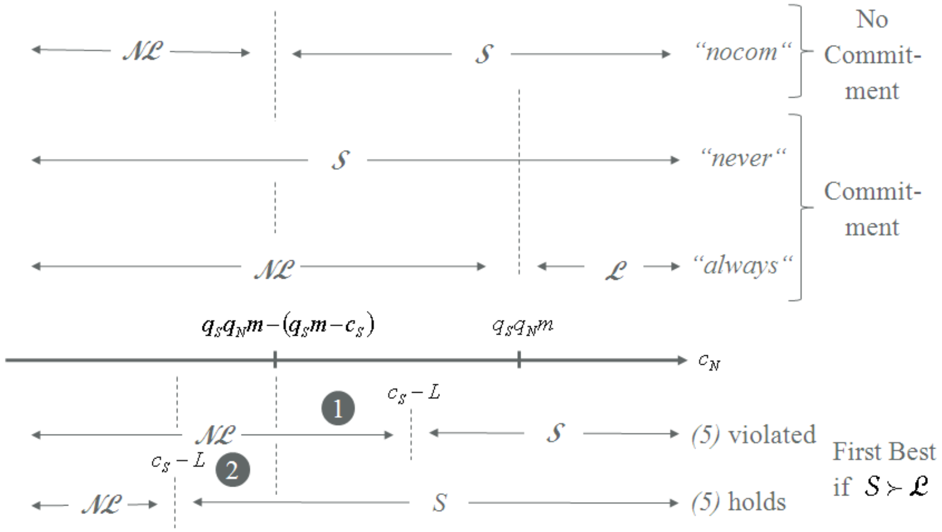

Figure 1: The welfare effects of no commitment

non-trivial way to achieve overall efficiency.[12]

We maintain the previous informational assumptions that the regulator knows the costs of investment for network capacity (i.e. L), but the costs for generation capacity are private knowledge of the firms.[13] A direct revelation mechanism consists of the following allocation and payment rules: An allocation rule $(\pi_0(\hat{c}), \pi_L(\hat{c}), \pi_S(\hat{c}), \pi_{NL}(\hat{c}))$, where $\hat{c} = (\hat{c}_S, \hat{c}_N)$ is a vector of messages, $\pi_0(\hat{c})$ is the probability that nothing is build, $\pi_L(\hat{c})$ is the probability that only the network is build, $\pi_S(\hat{c})$ is the probability that the generation capacity in the south is being build and $\pi_{NL}(\hat{c})$ is the probability that the generation capacity in the north and the network is being build. Thus it must hold that $\pi_0(\hat{c}) + \pi_L(\hat{c}) + \pi_S(\hat{c}) + \pi_{NL}(\hat{c}) = 1$.

A payment rule $(t_S(\hat{c}), t_{NL}(\hat{c}))$ describes the payments of the regulator to the builders of generation capacity in the South and in the North, conditional on the generation

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[12] We consider the case where the regulator can fully commit to her own investment into the network. However, even if she could not, by regulating the generation investment, she can always ensure that her ex post incentives to invest into the network coincide with the ex ante incentives.

[13] In the following we assume that there is one firm in the North, an one firm in the South. However, as long as generation costs are private values, generalizing the model to more than one bidder per region is straightforward. The mechanism developed in the following would just pick the cheapest bidder in the North and in the South, respectively.

capacity being build.[14]

With these definitions, the welfare function of the regulator as a function of the messages and the true types $c = (c_S, c_N)$ can be written as follows (where λ describes the shadow costs of public funds)[15]:

$$\begin{aligned} W(\hat{c}, c) &= -\pi_0(\hat{c}) q_S B - \pi_L(\hat{c})(q_S q_N B + (1+\lambda)\, L) \\ &\quad -\pi_S(\hat{c})(c_S + \lambda t_S(\hat{c})) - \pi_{NL}(\hat{c})(c_N + (1+\lambda)\, L + \lambda t_{NL}(\hat{c})) \end{aligned} \tag{6}$$

4.1 No shadow costs of public funds

Consider first the case where the government does not care about transfers, i.e. $\lambda = 0$. The next proposition shows that a generalized capacity market in the form of a reverse auction can be designed which implements the efficient allocation. Any of the standard auction formats would work, but for simplicity we concentrate on the Vickrey auction, i.e. a second price sealed bid auction.

To implement the efficient allocation, the bidders need to obtain a handicap to account for the additional network which is required in case the generation is built in the North, and to account for the different profit streams the generators would obtain (for the use of a handicap auction see also Eso and Szentes (2007)). A handicap G has the following function: the handicap G is added to the bid of the generator, which then describes his effective bid. The bidder wins the auction if his effective bid is smaller than the next lowest (effective) bid and the reserve price. His payment will be the next lowest (effective) bid or the reserve price, whichever is smaller, but with the handicap subtracted.

Proposition 4 *The regulator can implement the efficient allocation by a second price reverse auction with the following properties: The reserve price is set by* $r = \min(L +$

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[14] More generally, payments could differ in any of the four outcomes $(\emptyset, \mathcal{L}, \mathcal{S}, \mathcal{NL})$. However, since all parties involved are risk neutral, it is sufficient to analyze a payment scheme where investors only receive a payment in case they build generation.

[15] When network costs are added to the electricity bill, shadow costs can be small if the price elasticity of demand is small. With increasing elasticity of electricity demand, shadow costs become more important.

$q_S q_N B - q_S m, q_S B - q_S m)$. The bidder in the North obtains a handicap of $G_N = L + q_S q_N m - q_S m$. The bidder in the South obtains no handicap, $G_S = 0$.

Proof. From the point of view of a bidder with handicap G, the auction is like a standard second price auction where all other bids are subtracted by G, i.e. he wins if his bid is smaller than the other bids minus G, and his payment in case of winning is equal to the next lowest bid minus G. Textbook analysis then shows that it is a dominant strategy for the bidder to bid truthfully. Truthful bidding here implies that the bidder in the South will bid $c_S - q_S m$, i.e. his costs minus the expected profit he will earn on the energy market. The bidder in the North will bid $c_N - q_N q_S m$, to which the handicap is added. Thus, the effective bid is $c_N + L - q_S m$. This implies that the bidder in the south will win whenever $c_S < \min(c_N + L, r + q_S m)$, the bidder in the North will win whenever $c_N + L < \min(c_S, r + q_S m)$, and otherwise no generation will be built. In that case the regulator will either build the network or nothing, depending on whether $L + q_S q_N B$ is smaller or larger than $q_S B$. ■

The general idea behind the handicap auction and the reserve price in a capacity market is as follows. The reserve price decides whether or not new generation capacity should be built. Thus the reserve price measures the welfare loss which results from no investment into generation, given that investment into network capacity is optimal for that case. I.e., in the case where no network is going to be built if there is no additional generation, then the reserve price is equal to $q_S (B - m)$, which is the social excess incentive to build generation. If generation is to be built, the handicap decides where it should be build. The way the auction is set up, the bidder in the North obtains a handicap, which depends on the additional costs he creates by making an extension of the network necessary (L) and on the difference in private profits from investing in the North compared to investing in the South $q_S q_N m - q_S m$. Thus the handicap is equal to the left hand side of expression (5), i.e. the excessive private incentive to invest in the North compared to investing in the South.

By setting the auction up like this, the handicap takes care of the *investment forcing effect*. The handicap ensures that the bidder in the North only wins if this is in the social interest, and not because the bidder expects (forces) the government to install the network. Similarly, the specific form of the reserve price takes care of the *investment* *preempting effect*. If the Southern bid is lower than the (effective) Northern bid, it might still be the case that building in the South is suboptimal, since building the link only (or building nothing) might be socially superior. The reserve price ensures that building in the South takes place only if it is socially desired.[16]

4.2 With shadow costs of public funds

In this subsection, shadow costs of public funds are considered, i.e., $\lambda > 0$. We concentrate on direct mechanisms and apply standard techniques from mechanism design.

A bidder in the south with costs c_S will report truthfully, whenever

$$c_S = \arg\max_{\hat{c}_S} E_{c_N}[\pi_S(c_N, \widehat{c}_S)(q_S m - c_S + t_S(c_N, \hat{c}_S))] \tag{7}$$

Calling the profit of type c_S with message $\hat{c}_S$, $H_S(c_S, \hat{c}_S)$ yields:

$$\frac{dH_S(c_S, c_S)}{dc_S} = \left.\frac{\partial H(c_S, \hat{c}_S)}{\partial c_S}\right|_{\hat{c}_S = c_S} = -E_{c_N}[\pi_S(c_N, c)] \tag{8}$$

and thus

$$H_S(c_S, c_S) = \int_{c_S}^{\bar{c}_S} E_{c_N}[\pi_S(c_N, c)]dc \tag{9}$$

This leads to an expression for the expected transfer for type c_S:

$$E_{c_N}[\pi_S(c_N, c_S)t_S(c_N, c_S)] = H_S(c_S, c_S) + E_{c_N}[\pi_S(c_N, c_S)(c_S - q_S m)] \tag{10}$$

Therefore the expected payment from the regulator to the generator in the South is given by:

$$\begin{aligned} & E_{c_S} E_{c_N}[\pi_S(c_N, c_S)t_S(c_N, c_S)] \qquad (11) \\ = \; & E_{c_N}\left[\int_{\underline{c}_S}^{\bar{c}_S} \left(\int_{c_S}^{\bar{c}_S} [\pi_S(c_N, c)]dc + [\pi_S(c_N, c_S)(c_S - q_S m)]\right) dF_S(c_S)\right] \end{aligned}$$

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[16] We designed the handicap auction in such a way that the reference point is the South, i.e. the bidder in the South does not obtain a handicap (or a bonus). By construction, adding a fixed amount x to the handicap of both bidders, and to the reserve price, would lead to the same allocation.

Partial integration and some reformulations finally give:

$$E_{c_S}E_{c_N}[\pi_S(c_N,c_S)t_S(c_N,c_S)] = E_{c_S}E_{c_N}\left[\pi_S(c_N,c_S)(c_S - q_S m + \frac{F_S(c_S)}{f_S(c_S)})\right] \tag{12}$$

A similar analysis gives the expected payment for the generator in the north.

The welfare by the government can then be written as:

$$\begin{aligned} W \quad = \quad & E_{c_S}E_{c_N}\left[-\pi_0(c_N,c_S)q_S B - \pi_L(c_N,c_S)(q_S q_N B + (1+\lambda)L)\right. \\ & -\pi_S(c_N,c_S)(c_S + \lambda(c_S - q_S m + \frac{F_S(c_S)}{f_S(c_S)})) \\ & \left.-\pi_{NL}(c_N,c_S)(c_N + (1+\lambda)L + \lambda(c_N - q_S q_N m + \frac{F_N(c_N)}{f_N(c_N)}))\right] \end{aligned} \tag{13}$$

Proposition 5 *The optimal second best allocation will be (i) do nothing $\emptyset$, (ii) invest in the network only $\mathcal{L}$,(iii) invest in the South only $\mathcal{S}$,(iv) invest in North and in the network $\mathcal{NL}$, whenever the respective expression (i) to (iv) is the smallest among all four expression:*

$$\begin{array}{ll} (i) & q_S B, \\ (ii) & q_S q_N B + (1+\lambda)L, \\ (iii) & c_S + \lambda(c_S - q_S m + \frac{F_S(c_S)}{f_S(c_S)}) \\ (iv) & c_N + \lambda(c_N - q_S q_N m + \frac{F_N(c_N)}{f_N(c_N)}) + (1+\lambda)L. \end{array}$$

We obtain the following distortions:

Due to the costs of public funds, the decision whether to build nothing at all or whether to build a network only is distorted towards building nothing at all, as the network creates shadow costs of λL. The costs of public funds also distort the decision to build any of the generators. In addition, the informational asymmetry creates further distortions. In particular, overall investment in generation capacity will take place less often (due to the terms $\lambda\frac{F_i(c_i)}{f_i(c_i)}$ with $i \in \{N,S\}$). Also the decision whether to build in the North or the South is distorted because of informational asymmetry. Without informational asymmetry, the generator in the South will be build whenever costs are small enough and

$$c_S + \lambda(c_S - q_S m) \leq c_N + \lambda(c_N - q_S q_N m) + (1+\lambda)\, L \tag{14}$$

Now with informational asymmetry, building in the south takes place whenever

$$c_S + \lambda(c_S - q_S m) \leq c_N + \lambda(c_N - q_S q_N m) + (1+\lambda)\, L + \lambda(\frac{F_N(c_N)}{f_N(c_N)} - \frac{F_S(c_S)}{f_S(c_S)}) \tag{15}$$

Both the decision whether to invest and where to invest depend on the distribution of costs. For general functions $F_S(c)$ and $F_N(c)$, no standard auction with a constant handicap is able to implement the second best outcome.

5 Conclusion

We have analyzed the problem of investment coordination of network and generation capacities for the realistic case in which the costs of generation differ between different locations, and where different (private) locational choices for generation trigger different needs for (public) network extensions. Even absent asymmetric information problems, a lack of long-term commitment by the public network investor leads to inefficiencies: overinvestments as well as underinvestments into the network are possible. Overinvestment occurs, because generation providers invest without taking the costs of the network investment into account (investment forcing). Underinvestment occurs, because generation providers might choose specific locations in order to prevent socially useful network expansions (investment preemption).

If the government implements a capacity market, then without social costs of public funds the first best is implementable, however only if the capacity market takes differences in locations into account. A well-chosen reserve price decides if capacity should be added at all. A handicap that is added to the bids and which accounts for the divergence of private incentives and public incentives with regard to the location of the capacity steers any generation investments towards the efficient location. If there are social costs of public funds, there will be less investment into generation and also the decision where to invest is distorted. No simple capacity market exists to implement the second best.

As a policy recommendation, our analysis suggests that a well-designed capacity market can do more than only to address the problem of a possible underinvestment into generation capacity due to a "missing money problem". By use of an auction with a simple handicap scheme the capacity market can also address the problem of inefficient private locational choices, and it can also address the trade-off between using the cheapest generation sites and minimizing the network extension.

Except for the brief discussion of vertical integration and merchant transmission investors in Section 3.1, we have restricted attention to the case where investments in the network are undertaken directly by a benevolent regulator. Additional problems, which we did not address in this paper, arise from the regulation of a private network firm, or from non-benevolent regulators. Various papers derive regulatory contracts to provide efficient investment incentives for network firms (e.g., Leautier (2000) or Hogan, Rosellon, and Vogelsang (2010)) or deal explicitly with the problem of regulatory capture (Höffler and Kranz (2010)). None of these integrate into their analysis the issue of generation investments. Future research could try to expand our analysis of investment coordination towards these important additional issues.

6 Appendix

6.1 Analysis of the "full commitment" case

We take up the framework of Section 3.2 in which the regulator decides only on building the network and where there is asymmetric information with respect to c_N. We call "full commitment" a situation in which the regulator moves second, but can ex ante commit how to react to the firms' decisions. Obviously, such "full commitment" can never be worse than any of the regulatory strategies discussed so far, since "full commitment" can at least mimic any of those. However, the additional gain from "full commitment" is surprisingly small. The only strategic options the regulator gains in addition to the ones already discussed $(always, never, nocom)$, are the following: (i) to commit to building the link if and only if at the first stage nothing was built by the firms, or (ii) commit to building the link if the firms had built in the South or if nothing was built by the firms.[17] Both strategies avoid the *investment forcing effect* (since if the firms build in the North, the regulator commits not to build the link). The latter strategy additionally avoids the *investment preempting effect* (since the regulator commits to building the link if investment in the South occurred). Under both rules firms never build in the North, hence no information is ever revealed to the regulator. Therefore, as uncertainty becomes large and therefore if the probability mass on regions 1 and 2 of Figure 1 vanishes and is shifted to the left and right of these regions, there is no additional advantage from full commitment. Thus, the best full commitment can achieve in this case is to mimic *no commitment*.

6.2 Alternative institutional set-ups

In Section 3 of the main part of the paper, we focus on vertically separated networks where the regulator decides on the network extension. Alternative institutional setups are used in practice or are discussed, in particular vertically integrated firms and private "merchant" transmission investors. We briefly discuss the effects of these alternatives by comparing them to the outcome with a fully informed regulator without commitment (the framework of Section 3.1; "regulator decides on the network extension" in what follows). We also maintain from Section 3.1 the price formation for electricity, the assumption that generation investors move before the decision on the network is taken, and the assumption of "free entry".

Vertically integrated incumbent, with reimbursement of network cost: Consider a situation with an incumbent who owns all generation capacity which is initially installed. In addition, this incumbent decides on the network extension and he enjoys a first mover advantage with respect to generation investments (can invest in generation before en-

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[17] There are seven possible *full commitment* strategies to be considered. 1. "Build the link if there is investment in the South, if there is investment in the North, and if there is no investment." This is equivalent to *always*. 2. "Build the link if there was investment in the North, or if there was no investment." This is equivalent to *nocom*. 3. "Build the link if and only if there was investment either in the South or in the North." This is dominated by *always*, if we stick to the assumption that doing nothing is never optimal. 4. "Build the link only if there was investment in the South or if there was no investment." 5. "Build the link if and only if there was no investment." 6. "Build the link if and only if there was investment in the South". This is dominated by rule 4. 7. "Build the link if and only if there was investment in the North." This is dominated by rule 2.

trants can do so). The network is "regulated" in the sense of a cost-reimbursement rule, i.e., the integrated incumbent gets all network investments reimbursed (e.g., via network fees paid by final customers).

Lemma 1 *A set-up with a vertically integrated incumbent, with reimbursement of network cost, is welfare inferior to a set-up in which the regulator decides on the network extension.*

In Proposition 1, we describe the inefficiencies the regulator suffers from when she is unable to commit: the *investment preempting effect*, and the *investment forcing effect*. The same inefficiencies are present also with the vertically integrated incumbent since he has not to bear the cost of the network extension. However, there is an additional inefficiency added, a *foreclosure effect*. Consider a situation in which building the link only is optimal, and where the regulator can indeed implement this outcome. The former requires that $q_S q_N B < \min(c_S - L, c_n)$, the latter requires $q_S q_N m - c_N < 0$, i.e., private generation investments are not profitable with the link. A vertically integrated incumbent who does not build the link earns $\pi^o = q_S M + (1 - q_S) m + q_N m$. If he adds the link, profits are $\pi^L = q_S q_N 2M + q_S (1 - q_N) 2m + (1 - q_S) q_N 2m$. Therefore, $\pi^o > \pi^L$ if:

$$q_S M + (1 - q_S) m + q_N m - (q_S q_N 2M + q_S (1 - q_N) 2m + (1 - q_S) q_N 2m) > 0,$$

$$m + M q_S - m q_N - 3 m q_S - 2M q_N q_S + 4 m q_N q_S > 0,$$

$$m (1 - q_N) - q_S (M (2q_N - 1) + m (1 + 4q_N)) > 0,$$

which holds for q_S sufficiently small. For the integrated incumbent, the downside of building the link is that supply in the North can then negatively affect the price in the South, in particular if demand in the North is low. The only benefit to the integrated incumbent from building the link is that in cases of high demand in the South, with a connected network, this high demand can drive up the price also in the North. If this event is sufficiently unlikely, i.e., q_S is sufficiently small, then the integrated incumbent abstains from building the link.

A similar effect arises if the regulator wants to implement $\mathcal{NL}$, and is actually able to do so, which requires that building in the North is privately profitable, and more profitable than investing in the South, $q_S q_N m - c_N > q_S m - c_S$. If the link is built, we will never have excess demand (if the incumbent would not built it, an entrant would do so). As a consequence, if the integrated incumbent builds the link, he also adds generation in the North and earns $\pi^{NL} = q_S q_N m$. This is obviously smaller than π^o for M sufficiently large. Adding link and generation implies that the incumbent forgoes the chance to earn the high price M; for M sufficiently high, the integrated incumbent implements $\mathcal{S}$ (if $q_S m - c_S \geq 0$, or $\varnothing$ otherwise), instead of the welfare superior outcome $\mathcal{NL}$ which the regulator would implement.

In both of the two examples, the integrated incumbent abstains from building the link as a means to restrict the addition of generation in order to support higher prices; he does not invest to foreclose additional supply.

Vertically integrated incumbent, with private network investment: Consider the previous setup, but additionally assume that the integrated incumbent has to bear the cost of the network himself. Any outlays for the network need to be covered by the revenues generated on the electricity market. This, in a way, is closest to the "old world" prior to electricity market liberalization.

Lemma 2 *(i) If there is no investment forcing effect, then a set-up with a vertically integrated incumbent who bears the networks costs privately, is welfare inferior to a set-up where the regulator decides on the network extension. (ii) Only if there is a investment forcing effect, the vertically integrated incumbent who bears the network cost privately can lead to higher welfare compared to a set-up where the regulator decides on the network extension.*

Welfare inferiority is obvious from the above discussion of *foreclosure effects.* These become stronger, since building the link becomes even less attractive due to the network costs. However, different to the situation with a cost reimbursement for the integrated incumbent, we now can identify conditions under which integration performs strictly better than having the regulator without commitment power decide on the network. The reason is that the *investment forcing effect* can no longer occur. The *investment* *forcing effect* requires that $\mathcal{S}$ is preferred to $\mathcal{NL}$, i.e., $c_S < c_N + L$, but investment in the North (with network extension) is privately more profitable, $q_S m - c_S < q_S q_N m - c_N$, as long as the investor has to pay only for the generation, but not for the network. Now the integrated incumbent has to pay for the network, too. He would then invest in the North only if $q_S m (1 - q_N) < c_s - c_N - L$, which can never happen if $\mathcal{NL}$ is optimal (since the right hand side is then negative).

Merchant transmission investor: Imagine that a third private party undertakes the network investment. Such a "merchant transmission investor" bears all cost of building the network. His revenues depend on the usage of his network, i.e., the cases where the prices at the two nodes differ. Generally, the merchant investor will be able to capture some fraction of the gains from trade between the two nodes. From the perspective of the generators, this means that they have to pay some amount of money F for using the network for trading electricity. In our simple model, network usage occurs if and only if the demand in the South is high and no generation was added in the South (i.e., only with $\mathcal{NL}$ or $\mathcal{L}$). In these cases, without usage of the network the price in the South would be M, while with the use of the network it would only be $m < M$.[18] We therefore assume that the merchant investor's revenues are increasing in the difference $(M - m)$.

Lemma 3 *(i) If there is no investment forcing effect, then a merchant transmission investor leads to lower social welfare compared to a set-up where a regulator without commitment power decides on the network. (ii) Only if there is an investment forcing effect, the merchant transmission investor can lead to higher social welfare compared to a set-up where the regulator decides on the network extension.*

Without the *investment forcing effect*, the regulator might face the investment preempting effect. Investment preemption can not be solved by a merchant transmission investor. Whenever it is more profitable for the generators to add capacity in the South than to add them in the North (although this might be efficient) they will do so - independent of who decides on the network. Neither the regulator nor the merchant will

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[18] The only exception is if $\mathcal{L}$ is implemented, and demand in the South and in the North is high. Then even with the network, the overall price is M. However, also in this case it is reasonable to assume that some trade occurs, at least if we would allow for smaller, incremental trading volumes, since without the network, the price in the North is m, while it is M in the North.

add a network once generation addition in the South ensures there will never be any shortage at either node. However, the merchant introduces an additional inefficiency. Consider the case where $\mathcal{NL}$ or $\mathcal{L}$ is optimal. The merchant can make money only if the demand in the South is high. Thus, his profits increase in q_S. Thus, if q_S is sufficiently small, the merchant will not invest (since he always has to bear the cost L), while absent the investment preempting effect (for which there is no difference between regulator or merchant deciding on the investment), the regulator can always implement the desired outcome.[19]

In addition, whenever q_S is large, implying good chances for the network to be built by the merchant, it will not be needed, since for high q_S it is increasingly privately profitable to invest in the South (instead of investing in the North), and it also tends to become socially more desirable to implement $\mathcal{S}$ instead of $\mathcal{NL}$ or $\mathcal{L}$.

However, a merchant transmission investor might be beneficial as an instrument to avoid the *investment forcing effect*. With the merchant transmission investor, the generators lose some revenues F from trading between North and South. Thus, inefficient investment forcing only happens if $q_S m (1 - q_N) + F < c_N - c_S < L$ while at the same time a merchant would indeed build the network if there had been generation addition in the North, which requires q_S to be large and L to be small. Thus, the conditions for the *investment forcing effect* to occur are more restrictive compared to a situation where the regulator decides on the network extension.

To summarize, it is not surprising that a merchant transmission investor tends to worsen the situation. *Investment forcing effect* and *investment preempting effect* are a result of the separation of the decision of generation and network. This separation is not solved by the merchant transmission investment; even more, the merchant does not account for the social benefit of the network, and therefore adds additional inefficiencies. The only circumstances in which they can be beneficial are – ironically – situations where no network should be build, i.e., where delegating the network decision to the merchant is a credible mechanism not to build the network.

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[19] Recall that whenever the regulator prefers $\mathcal{L}$ to $\mathcal{NL}$ (which requires $q_S q_N B + L < c_N + L$), adding generation in the North is unprofitable (since by assumption $B > m$, and profitable Northern investment requires $q_S q_N m > c_N$).

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