Regulation of Interconnector Investments in Natural Gas Networks – An Experimental Evaluation

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Abstract:

We conduct economic laboratory experiments in order to compare the performance of rate of return regulation and regulatory holiday regulation in providing incentives for an optimal expansion of natural gas pipeline capacity. We additionally evaluate in how far the introduction of long-term financial transportation rights (LTFTR) in each of these two regulatory schemes affects overall performance of the schemes in general as well as the optimality of pipeline expansion decisions in particular. We find that although neither regulatory holidays nor LTFTR significantly affect static efficiency, general efficiency, profit distribution and spot prices are significantly affected.

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1. Background, Research Agenda and Methodology

1.1 Background

Regulation of investments in network infrastructure has attracted and continues to attract a considerable degree of attention both from the academic community[1] as well from policy makers. On one side, the natural monopoly nature of many network industries, which is predominantly characterized by lumpiness and irreversibility of investments in particular and sub-addditivity of cost functions in general, necessitates access regulation which prevents the infrastructure-owner from charging significantly supra-competitive prices from network-access seeking parties. Conversely, the prospect of effective regulation in that sense decreases the expected profitability of building new network infrastructure for a potential investor, diminishing the chance to obtain a socially optimal level of investments in the first place. Furthermore, regulation intended to stipulate investments should also take into account how to compensate a potential investor for the ex-ante risk of stranded assets.

The European Regulators' Group for Energy and Gas (ERGEG) has initiated Gas Regional Initiatives (GRI) to determine characteristics of an environment, which stipulates a sensible expansion of the natural gas-pipeline capacity between the member states. The evaluation of the suitability of regulatory regimes to overcome the previously mentioned potential conflict of goals is one essential task for the success of this undertaking. Clearly though, when trans-national investments are considered, other important factors are of significance as well, most importantly the trans-border coordination of investments as well as external effects caused by one investment decision on existing or future investments of other investors. However, while we fully acknowledge the importance of both the coordination and externality issues, we do not explicitly consider them in this paper and do instead concentrate on the comparative evaluation of the incentive properties of regulatory schemes with regard to optimal investment decisions made by a single investor. This self-imposed restriction ensures that we can unanimously link observed differences in the optimality of investment decisions to the incentive properties of the regulatory schemes that we intend to evaluate, permitting a valid and

[1] Vogelsang 2005 provides a good overview of the relevant literature.

robust assessment of their properties. We thus intend, with this research project, to assist policy makers in choosing a particular regulatory scheme for the actual access regulation of interconnector capacity once the coordination and externality issues have been addressed. The identification of proper mechanisms to achieve this substantial goal is not part of this research effort although we strongly encourage the investigation of these issues in future research.

This paper proceeds as follows: The next two subsections motivate our choice of regulatory regimes and provide information on the methodology to be used to evaluate and compare their performance. The research questions of this paper will also be outlined. Section 2 details our research design while Section 3 presents results. In Section 4 we analyze these results and provide a conclusion in Section 5.

1.2. Research Agenda and Research Questions

Regulation of network industries, be it telecommunications, energy or gas, has manifested itself in a considerable number of regulatory schemes. Cost-plus regulation, price-cap regulation as well as revenue caps come easily into mind, as well as rate of return (RoR) regulation. These represent arguably the most prevalent choices of regulatory schemes aiming at an efficient regulation of existing network capacity. In fact, RoR-based regulation is used in some member states of the European Community (EC) to regulate gas pipelines. This circumstance on its own, which also ensures familiarity of the concept with participants of the GRI[2], turns it into a suitable candidate for comparison with regulatory schemes which explicitly strive to address the potential investment issue hinted at in the previous section. However, RoR regulation is potentially not without problems when its properties regarding the induction of an optimal level of investments are considered. If the permitted rate of return per unit of capital is limited, RoR regulation might induce the regulated monopolist to install an inefficiently high level of capital in order to maximize its regulated profits, a phenomenon which is well known as the Averch Johnson Effect. In order to counter this inefficient

[2] The majority of this research effort is funded by the Dutch Energy Regulator (NMa) in the context of discussions within the GRI framework, hence a certain level of familiarity of the involved regulation to GRI participants was mandatory. We express our deep thanks to the NMa as well to CentER for the financial support.

behavior, so-called “used and useful” rules can be implemented. Under a used and useful rule, the regulated monopolist only receives a return for the particular amount of capital which ex-post turns out to be necessary to provide the service. The used and useful rule hence eliminates the incentive for a transmission system operator to over-invest. However, if a strict (ex-post) used and useful rule is implemented, the potential investor bears the full risk of stranded assets while its profit opportunities in case of a successful investment are still curtailed by RoR regulation. As indicated in section 1.1, this might conversely induce the regulated monopolist to not invest enough, as the ex-ante expected return of any investment (including efficient ones) decreases.

One category of regulatory schemes which intends to specifically address this potential issue of underinvestment due the combination of risk of stranded assets and curtailed profits are “regulatory holidays”, as discussed by Gans & King 2003. Under Regulatory Holiday Regulation, a potential investor is exempted from access regulation for a pre-specified amount of time. This exemption is intended to address the following issue, which potentially arises under the aforementioned regulatory regimes, such as RoR with a used and useful rule in place: If such regulation is applied and the investment turns out to be successful, an investor’s profits are truncated by regulation. At the same time, if the investment turns out to be unsuccessful, the investor still has to bear the full costs of that failure. Thus, for a given level of ex-ante risk, an investor’s expected profits from an investment under RoR regulation with a used and useful rule is potentially lower than under regulatory holiday regulation. Consequently, a potential investor might either reduce its level of investment below the optimal level or not invest at all. Further contributing to our decision to investigate the properties of regulatory holiday regulation is the circumstance that the Second Gas Market Directive (2003/55/EC, Article 22) has provisions for granting a regulatory holiday for investors establishing new pipeline capacity, albeit under very strict conditions.

Two additional factors motivate our choice to investigate the properties of regulatory holiday regulation: First, while the argument above suggests that investments into pipeline capacity might exceed those achievable under RoR regulation, regulatory holidays effectively provide the TSO with the means to monopolize over (residual) pipeline capacity demand. Thus one can as well argue that regulatory holidays incentivize the TSO to decrease or delay pipeline capacity expansions compared to RoR regulation. One goal of this project is thus to evaluate which effect dominates, although it is clearly evident that the outcome will be dependent on the amount of risk inherent in our capacity demand specification. The second factor why to choose regulatory holidays is of a more practical nature and based on the defensible assumption that a regulator can probably easier commit to a temporary exemption from access regulation than to higher prices. Summarizing the discussion so far, we are confident that choosing regulatory holiday regulation for a comparative evaluation is a sensible decision.

As discussed above, regulatory holiday regulation grants temporarily unregulated profits to an investor in order to compensate it for an ex-ante risk of stranded assets[3]. A different approach towards at least partially overcoming a potential investor's reluctance to invest due to fear of stranded assets is by providing that investor with a source of information on future demand for transportation capacity. We choose periodic auctions of long-term financial transportation rights (LTFTR) as means to achieve this. LTFTR are financial hedges, which entitle their holders, in our case gas-shippers which are active in capacity spot markets, to a share of the revenues an investor (which from now on we assume to be a Transportation System Operator, TSO) receives in the capacity spot markets.

There are several reasons for our decision to assess LTFTR within the context of the two aforementioned regulatory regimes. First, over their validity period, which spans over several spot market periods, they should provide the potential investor with information on future demand. By choosing an appropriate level of investments given the aggregated demand information acquired in an LTFTR auction, a TSO can ensure that no assets will be stranded during that time and at least cost recovery is guaranteed. If risk of stranded assets was indeed a major obstacle for investments, the introduction of periodic LTFTR auctions in addition to spot market transportation capacity auctions should diminish that obstacle. Should such an effect exist, we can gauge and compare it to the assumed positive effect on the level of investments by implementing regulatory holiday regulation instead of RoR regulation and identify potential interactions between the regulatory schemes and the

[3] Initial discussions with Transportation System Operators (TSO) taking part in the GRI quoted the risk of stranded assets as the potentially most severe hindrance towards investments in interconnector capacity in an environment relying (solely) on competitive transportation capacity allocation. The involved regulatory authorities strive for competitive allocation of capacity to the largest extent possible.

introduction of LTFTR. Similarly, we can assess in how far a TSO can reach optimal investment decisions if it only relies on competitive spot market sales. Put differently, we want to seize the opportunity to assess in how far the addition of long term demand information contributes to an optimal pipeline capacity expansion and in how far this effect differs for the two types of regulation.

Second, the income of the TSO is decoupled from potentially highly volatile spot market revenues: If a TSO covers (must cover) all pipeline capacity with LTFTR sales, it will need its entire spot market income to compensate LTFTR holders (the shippers). The TSO then derives its income solely from LTFTR sales, which are constant over the entire validity period of the LTFTR. Third, LTFTR are not only beneficial for a TSO but also for shippers, as acquiring LTFTR hedges a shipper both against not obtaining capacity in the spot markets and against having to pay “too high” spot market prices, by generating a payment for its holder which is independent from a successful acquisition of transportation capacity in the spot market.

Our research questions are thus as follows:

- What is the relative performance of RoR with used and useful rules and regulatory holiday regulation in an environment, which reflects essential features of natural gas-transportation markets?
- How does the inclusion of long-term demand information by means of periodic LTFTR auctions affect overall performance of the aforementioned regulatory schemes?

1.3 Economic Laboratory Experiments

Our methodology of choice for the actual evaluation of the discussed regulatory schemes as well as the effect of introducing periodic LTFTR auctions are economic laboratory experiments, which have a successful record in assessing the properties of regulatory schemes intended for implementation in network industries. Please confer to Kiesling 2005 for an excellent summary of the work done in that regard.

In laboratory experiments, real humans, the so-called subjects, are put in a controlled laboratory environment specified by the experimenter. Usually, and also in case of the research conducted for this paper, the subjects are seated in separate compartments of a computer room and make inputs on a computer screen. For example, in our experiment subjects attaining the role of shippers are asked to indicate how much they are willing to pay for pipeline capacity this way. Based on subject-inputs, a computer program calculates market outcomes and profits depending on the rules specified by the experimenter, which for the purpose of this research project mirror the different regulatory regimes. As the experimenter has full control both over the environment as well as the rules of interaction, the market outcomes can be compared with theoretical benchmarks. Furthermore, ceteris-paribus comparisons between the regulatory regimes are possible as the experimenter can ensure that only particular interaction rules or features of the experimental environment change. Hence, the cause for observed changes in subject behavior can be causally linked to changes in interaction rules and / or the experimental environment while any influence from factors outside the experimental setup can be ruled out. This benefit cannot be achieved by any other research methodology.

Based on their decisions and the resulting market outcomes, subjects receive a performance-based payment. This ensures that the subjects behave in a way they deem optimal given the environment and the interaction rules. The significant potential benefit is that subjects motivated in this way might uncover previously unexpected strategies to maximize their own benefit at the cost of social welfare / efficiency. The relevance for the task at hand is obvious: At comparatively low costs it can be prevented that a mechanism with undesirable efficiency-properties is implemented. The possibility to uncover unintended possibilities for efficiency decreasing strategic behavior is yet another benefit of laboratory experiments that cannot be realized with other methodologies.

Finally, the structure of an experimental setup shall be described. Every experiment is structured into treatments and sessions. A treatment is a particular set of environmental features and interaction rules. Treatments differ in the values that so called “treatment variables” attain. In our experiment, there are two treatment variables: “Regulatory scheme” (RoR or Regulatory Holiday Regulation) and “LTFTR” (LTFTR present / not present). Hence, there are four possible combinations of these treatment variables (which will be discussed at length in the following section) and hence four different treatments. We collect data for each of these treatments in so called “sessions”. During a session, the experiment is conducted with a particular set of subjects. Subjects take only part in one session in order to avoid that their behavior in one treatment is biased by a preceding exposure to another treatment. Several sessions are conducted for each treatment in order to ensure that the observed results do not hinge on a particular and accidental subject group composition. The treatment / session structure is also reflected in the statistical tests that we perform and report in section 3. We utilize statistical models that account for such non-systematic heterogeneity on the session level.

The upcoming section discusses our experimental design, that is the actual implementation of the regulatory schemes as well as the experimental environment in which they are assed in detail. Proceedings during the experiment are also discussed.

2. Experimental Design

2.1. General Design and Procedures

As outlined, we intend to identify the properties of two regulatory schemes as well as their interactions with LTFTR auctions. Hence, as elaborated in the previous section, we devise a design with four treatments, reflecting all possible combinations of the treatment variables "Regulatory Scheme" and "LTFTR". Four sessions for each of the four treatments were conducted at the CenterLab facilities at Tilburg University using the z-tree software (Fischbacher 2007). In every treatment, one subject takes on the role as TSO while four subjects take on roles as shippers. The roles are assigned based on the performance of the subjects in a quiz, which is used to ensure subjects' understanding of procedures. The subject exhibiting the best performance was assigned the role as TSO. Every subject takes only part in a single session. A typical session lasts for approximately three hours of which 75 minutes on average were used for going through written instructions as well as for answering questions of the subjects. Subjects earned on average 25 Euros for their participation.

In all four treatments, the subjects interact over two separate thirty period spot market cycles, which are subdivided into five six-period blocks starting in periods 1, 7, 13, 19 and 25. The aggregated capacity demand function of the shippers is given by:

$$D_t = a - \frac{2b}{g_t} q_t \tag{I}$$

a and b are fixed parameters, q_t is the amount of spot capacity offered by the TSO in the spot market and g_t is a growth parameter. $g_t = 1$ in the first period of each thirty period cycle and grows linearly by approximately 6% per period in the first two six period blocks (that is until period 12). It remains constant from period 12 up to period 15 and declines linearly by approximately 6% per period during periods 16 to 18. For the remaining two six period blocks, that is from period 19 onwards, g_t linearly increases again by approximately 6% per period. The subjects possess no information about the specification of aggregate demand. The competitive equilibrium pipeline capacity is equal to 8 capacity units in period 1 and equal to about 19 units in period 30, and the TSO starts with a pipeline capacity of 4 units. Note therefore that another crucial design choice is the assumption of growing aggregate demand for pipeline capacity in the long run. Aggregate demand in (I) is distributed over the Shippers. That is every shipper faces a particular part of the aggregate demand function which, if combined with the demand functions of the other Shippers, yield the aggregate demand function in (I).

Shippers learn about their individual demand (valuation) for capacity[4] in the first period of each six-period block. Each Shipper only knows its own demand and has no direct information on aggregate demand. The TSO's sole source of demand information is the spot capacity auctions and, depending on the treatment, the shippers' aggregated bids in the periodic LTFTR auctions. We therefore implement an information asymmetry between the TSO and the Shippers, which intends to mirror the actual situation in the market.

Subjects can, at the revelation of spot demand information in the first period of every six period block (periods 1, 7, 13, 19 and 25), decide to raise part of their valuations by pre-specified amounts of experimental currency units for all spot market periods until the subsequent revelation of demand. If they do so, they incur a fixed cost ("commitment cost") in every period until that point. This design choice captures potential must-serve demand obligations. In all treatments, the TSO can invest (expand pipeline capacity) every three periods, i.e. in the first and fourth period of each six period block (that is periods 1, 4, 7,). The expansion itself is costless, but a fixed cost per pipeline capacity unit is incurred in every period until the end of the thirty period cycle, regardless of whether it is actually used to provide spot capacity or not. Investments into pipeline capacity are thus irreversible and we thereby introduce a degree of lumpiness of investments, which clearly represents another essential feature of interconnector investments as outlined in section 1. Illustrations 1a and 1b in Appendix D provide graphical representation of the sequence of actions taken by the subjects over the course of each six period block.

[4] The following convention shall apply: "spot capacity" designates the amount of capacity on the pipeline that the shippers acquire during spot market auctions, whereas the term "pipeline capacity" is used to designate the actual physical size of the pipeline. A TSO's investment decision hence concerns the expansion of pipeline capacity. One unit of pipeline capacity is required for the provision of one unit of spot capacity.

2.2. Treatment-specific Procedures

We shall now discuss specific procedures in each of the four treatments[5], which are:

- Rate of Return without LTFTR (henceforth "Baseline treatment")
- Regulatory Holiday without LTFTR (henceforth "Holiday treatment")
- Rate of Return with LTFTR (henceforth "LTFTR treatment")
- Regulatory Holiday with LTFTR (henceforth "Holiday & LTFTR treatment")

In the **Baseline treatment** an auction for spot capacity is conducted at the onset of every period. If the period is also an investment period (1, 4, 7, …) it is conducted after the TSO decides on the expansion of pipeline capacity. Shippers submit bids for transportation capacity, which are aggregated and presented to the TSO, which then decides on the amount of pipeline capacity to be used for the provision of spot capacity. The price for transportation capacity, which all successful bidders have to pay is equal to the lowest accepted bid[6]. A price cap is in place such that if the resulting capacity spot price exceeds that cap, the TSO receives the capped price (and hence a pre-specified return) per unit of pipeline capacity actually used for providing transportation capacity. As the TSO hence obtains the specified return only for units of pipeline capacity that it actually offers to the Shippers, there is indeed a used and useful rule as described in section 1.2 in place. The difference between shipper payments and TSO spot market income in case of a binding spot market price constraint is kept by the computer[7]. The spot markets of each period are the only means for the TSO to offer transportation capacity to the shippers.

Proceedings in the **Holiday treatment** are entirely identical. The only difference is that for spot capacity which can only be offered because the TSO has increased pipeline capacity during the current six period block, the TSO is entitled to obtain the spot price determined in the spot auction even if that price is higher than the price cap mentioned in the previous section. The price cap though

[5] The data gathering sessions for the Baseline and the LTFTR & Holiday treatments were funded by NMa, the sessions for the remaining two treatments by CentER.
[6] We implement this particular auction / price setting rule as experimental research by other authors has established that this pricing rule has no evident detrimental effects on efficiency.
[7] We make no assumptions on the utilization of this amount, as it is mostly a political decision in reality. We do however clearly consider it when computing total efficiency and label it as "regulator income" for the remainder of this paper

is in place for any unit of spot capacity, which could be offered with pipeline capacity that already existed before the start of the current six period block. Hence, a particular expansion of pipeline capacity is only unregulated until the beginning of the next six period block. The duration of the regulatory holiday is thus at most six spot market periods (three for pipeline capacity which has been added in the fourth period of a six period block).

Compared to the baseline treatment, the **LTFTR treatment** adds periodic LTFTR auctions. One unit of LTFTR pays its holder in every spot market period over the course of its validity period the spot price for capacity in that period. Shippers submit bids for LTFTR in the first period of each six period block, hence in period 1, 7, 13, 19 and 25 and do so before they decide on raising a part of their valuations and also prior to the capacity spot market of that period. The rules in the LTFTR auctions are the same as in the spot auction discussed so far, that is all winning bidders receive LTFTR for the same price and the TSO decides on the number of LTFTR to offer after seeing the aggregated bids of the shippers. The TSO is required to offer LTFTR to exactly cover its entire pipeline capacity. Put differently, whenever the TSO decides to issue additional LTFTR he is required to back this up with additional capacity and vice versa. Practically, this means that there is an LTFTR auction every third period, that is at the instances when a TSO decides on whether to increase pipeline capacity or not. At both these instances, the TSO is presented with the aggregated bids the shippers submitted in the first period of the current six period block. Hence, if in the fourth period of a six period block the TSO decides to increase pipeline capacity, the new spot price for capacity is calculated using the aggregated bids the shippers submitted in the first period of the current six period block. The TSO faces a price cap on all LTFTR units it sells and is required to offer its entire pipeline capacity in the capacity spot market. Note well that due to the fact that the TSO must sell LTFTR for its entire pipeline capacity, the only source of income for the TSO is the sale of LTFTR at the regulated price.

The proceedings in the **Holiday & LTFTR treatment** are similar compared to those in the LTFTR treatment. However, the TSO enjoys a much higher degree of freedom to which extent it covers the spot capacity it offers with LTFTR. In fact, the only requirement is that the TSO must, in the LTFTR auction at the beginning of each six period block, offer enough LTFTR to cover all pipeline capacity which has been in place previously. As in the LTFTR treatment, there is a price cap in place for these LTFTR units. The TSO can obtain unregulated profits by increasing pipeline capacity and not offering LTFTR for that capacity. If the TSO does so, its income from spot sales will exceed the amount it has to pay to the holders of LTFTR, the rest being unregulated profit for the TSO. However, at the onset of the next six period block, the TSO is required to offer LTFTR for its entire existing capacity once more, forcing it to increase pipeline capacity again if it intends to obtain unregulated profits. Hence the regulatory holiday for newly installed pipeline capacity lasts at most for six spot periods (three if the TSO expands capacity in the fourth period of the current six period block).

The following section provides summary statistics on the data obtained by means of the experiments.

3. Results

3.1. Statistical Model & Benchmark

Before we continue with the presentation of the results obtained by means of the experiment described in the previous sections, we first describe the statistical model utilized to obtain these results as well as the benchmark to which we compare the performance of the particular treatments.

Our principal statistical model is a mixed effects regression of the type:

$$Y_{it} = \alpha + \beta_1 \cdot LTFTR_i + \beta_2 \cdot Holiday_i + \beta_3 \cdot (LTFTR_i \cdot Holiday_i) + \upsilon_i + \varepsilon_{it} \qquad \text{(II)}$$

Y_{it} is the dependent Variable of interest. α ("Constant" in tables 1-3) is a fixed constant for all treatments. $LTFTR_i$ and $Holiday_i$ are zero-one dummies attaining the value of one in sessions of treatments in which LTFTR auctions are held or regulatory holidays are implemented respectively. $LTFTR_i \cdot Holiday_i$ is a dummy attaining the value of one only in the LTFTR & Holiday treatment. β_1 (labeled "LTFTR" in the tables to follow) measures thus the effect of having LTFTR auctions compared to not having them, β_2 ("Holiday") measures the changes of introducing a regulatory holiday over rate of return regulation and β_3 ("LTFTR*Holiday") measures the interaction in case LTFTR and a regulatory holiday are contemporaneously in place. These treatment effects are modeled as fixed effects. υ_i is a random intercept accounting for session effects (subscript i is used to designate the individual sessions). Finally, ε_{it} designates a random error term. We do neither report the session effects nor the random error terms for reasons of brevity. The regressions used to obtain the results provided in the tables are based on the data collected during the second 30 period cycle in each session, as by this time we can confidently assume that the participants are familiar with the experimental proceedings.

In addition to the mixed effect estimation outlined above we also performed pair wise nom-parametric Mann-Whitney tests between any two treatments. We do however only report[8] these if the obtained treatment effects go into the opposite direction than the ones obtained with the mixed effects model or in case the significance level of the effects is different.

[8] The results are available upon request of course.

We compare the observed prices, pipeline capacities and aggregate income (which is a measure of total social welfare) in each of the treatments to a full competition, i.e. "first-best" benchmark. The respective benchmark values, i.e. optimal capacity spot prices, optimal pipeline capacity and optimal aggregate income are obtained by means of a dynamic optimization over the entire 30 period horizon over which the subjects interact. The optimization program behaves like a benevolent social planner with the aim to maximize aggregate subject income and which has full information on aggregate demand in every period at the onset of period 1. Appendix C provides a comprehensive overview of the optimization problem that is solved.

Note thus that we utilize a benchmark for all treatments that is independent of subject behavior exhibited during those treatments. This includes the baseline treatment as well: The baseline treatment is labeled as "baseline" not because we utilize it as a benchmark but solely because it is the treatment in which both treatment variables attain a value of zero. An additional benefit of using the benchmark as defined above is that we can not only establish a relative ranking between the four treatments but also obtain an absolute measure of efficiency, as we indeed measure performance in terms of a first-best solution. Admittedly, that represents the toughest performance benchmark possible.

3.2. Market Outcomes & General Efficiency

Please consider Table 1, which provides information on the deviations of actually installed pipeline capacity and spot prices for capacity from the first-best benchmark as well as general efficiency, which is defined as the quotient of the combined profits of the TSO, the shippers and the regulator that were actually realized and those which would be obtained under the first-best benchmark.

Table 1: Market Outcomes & General Efficiency

	Coef.	Std. Error	z	$P > \|z\|$	95% Conf. Interval	
$\boldsymbol{K_t - K_t^*}$						
LTFTR	-0.475	0.833	-0.57	0.568	-2.107	1.157
Holiday	-0.175	0.833	-0.21	0.834	-1.807	1.457
LTFTR*Holiday	-1.375	1.178	-1.17	0.243	-3.683	0.933
Constant	-2.575	0.589	-4.37	0.000	-3.729	-1.421
$\boldsymbol{P_t(K_t) - P_t^*(K_t^*)}$						
LTFTR	21.633	6.293	3.44	0.001	9.299	33.968
Holiday	9.625	6.293	1.53	0.126	-2.710	21.960
LTFTR*Holiday	-0.542	8.900	-0.06	0.951	-17.986	16.902
Constant	14.758	4.450	3.32	0.001	6.036	23.480
General Eff.						
LTFTR	-0.068	0.030	-2.23	0.026	-0.128	-0.008
Holiday	-0.058	0.030	-1.91	0.057	-0.118	0.002
LTFTR*Holiday	-0.050	0.043	-1.15	0.251	0.134	0.035
Constant	0.945	0.022	43.81	0.000	0.902	0.987

We infer that in all treatments the installed pipeline capacity falls short of the theoretical optimum. The coefficients suggest that the amount of capacity is highest in the Baseline treatment (where it falls on average about two and a half units short of the optimum) and lowest in the LTFTR & Holiday treatment, where it falls short of about four and a half units on average. While the results in Table 1 suggest that these differences are not significant, using pair wise Mann-Whitney tests we find that the difference between optimal and actual pipeline capacity is significantly smaller in the Baseline treatment compared to all other treatments and significantly higher in the LTFTR & Holiday treatment than in all other treatments. Figure 1 in Appendix A illustrates the development of pipeline capacity over time.

Concerning the difference between actual capacity spot prices and competitive spot prices (which were calculated on the assumption that an optimal level of pipeline capacity is made available), we find that this difference is significantly larger than zero in all treatments, meaning that compared to a full competition benchmark prices are too high. Prices are closest to the optimum in the Baseline treatment and furthest away in the treatments with LTFTR markets. The Mann-Whitney tests fully concur with these results and also reveal that prices in the Holiday treatment are significantly higher than those in the baseline treatment. Figure 2 in Appendix A illustrates spot price development.

Finally, we obtain that general efficiency as defined above is highest in the baseline treatment at almost 95% of the theoretical maximum. We also find that general efficiency in the LTFTR treatment is about 7 percentage points, general efficiency in the Holiday treatment about 6 percentage points lower. We can also infer that general efficiency in the LTFTR & Holiday is by far the lowest. Once more, the results obtained with pair wise Mann-Whitney tests fully concur. Figure 3 in Appendix A provides a graphical illustration of the development of general efficiency over the periods of the second thirty period cycle.

Thus the data in Table 1 reveals a very good overall performance of the Baseline treatment, both in absolute terms and also relative to the other three treatments. In the following section, we attempt to uncover potential causes for these differences. However, please consider first Table 2 which provides information on the profits of the TSO, the individual shippers as well as the regulator.

Table 2: Profits

	Coef.	Std. Error	z	$P > \lvert z \rvert$	95% Conf. Interval	
Profit TSO						
LTFTR	-0.050	7.195	-0.01	0.994	-14.152	14.052
Holiday	24.458	7.195	3.40	0.001	10.356	38.561
LTFTR*Holiday	-10.992	10.176	-1.08	0.280	-30.936	8.952
Constant	44.550	5.088	8.76	0.000	34.578	54.522
Profit Shipper						
LTFTR	-20.229	17.289	-1.17	0.242	-54.114	13.656
Holiday	-17.327	17.289	-1.00	0.316	-51.212	16.558
LTFTR*Holiday	-6.052	24.450	-0.25	0.804	-53.973	41.869
Constant	124.913	12.225	10.22	0.000	100.952	148.873
Profit Regulator						
LTFTR	43.742	56.237	0.78	0.437	-66.481	153.965
Holiday	15.292	56.237	0.27	0.786	-94.931	125.515
LTFTR*Holiday	-4.242	79.532	-0.05	0.957	-160.121	151.637
Constant	87.608	39.766	2.20	0.028	9.669	165.548

Starting with the Profit of the TSO, we find that profits in the Baseline and LTFTR treatments are all but identical, but significantly higher in treatments with regulatory holiday regulation. The Mann-Whitney tests concur with these findings, they do however in addition establish that the profit in the Holiday treatment is also significantly higher (only slightly missing the 5% significance level) than in the LTFTR & Holiday treatment. Concerning shipper profits, Table 2 suggests that they are highest in the Baseline treatment, with profits in the LTFTR and Holiday treatment lower but about equal to each other. Shipper profits in the LTFTR & Holiday treatment are lowest, although this finding is like the ones reported above not significant. The pair wise Mann-Whitney tests do however confirm the relations above and yield that shipper profits in the baseline treatment are significantly higher than both the profits in the Holiday and the LTFTR treatment which themselves are significantly higher than those in the LTFTR & Holiday treatment. The mixed effects regression does not uncover any significant differences in regulator profits between the treatments, although in tendency they seem to be lowest in the Baseline and highest in the LTFTR & Holiday treatment.

Finally, Figures 4a and 4b in Appendix A illustrate that in treatments with LTFTR markets, the LTFTR price is consistently lower than the spot price for capacity, especially in the first periods of the cycle. Using t-tests (see Table 4 in Appendix B) we establish that this difference is highly significantly different from zero. In addition, we find, utilizing t-tests on spot market bids of shippers in both the LTFTR and the LTFTR & Holiday treatments, that shippers bid higher (and even higher than their induced valuations) if their spot demand is hedged. The tendency to overbid generally increases the lower the hedged valuation is. The results are presented in Tables 5a and 5b in Appendix B.

The next section attempts to identify the causes for the observed differences between the treatments.

4. Analysis

4.1. Static Efficiency

In the previous section we established that the general efficiency in the baseline treatment was significantly higher than in all other treatments. General efficiency as described above is a product of static (allocative) efficiency and dynamic (investment) efficiency. Hence by looking at either of these components, we can trace the causes for differences in general efficiency.

Static efficiency measures how efficient the spot market auction allocates the currently available capacity to the bidders. Static efficiency is therefore high when the bidders with the highest valuations receive the capacity on the spot market and low when those shippers fail to acquire capacity. For "K" available units of spot capacity in period "t", we define static efficiency in period t as the quotient of the sum of the valuations of shippers who actually obtain the K units and the sum of the K highest valuations. In addition, we consider the efficiency of the spot market's price signal. We compare the theoretical spot price which would prevail if the price was set by the K-th highest valuation with the actual spot price.

Table 3: Static Efficiency

	Coef.	Std. Error	z	$P > \|z\|$	95% Conf. Interval	
Allocative Eff.						
LTFTR	0.008	0.043	0.18	0.861	-0.077	0.092
Holiday	0.065	0.043	1.51	0.130	-0.019	0.150
LTFTR*Holiday	-0.062	0.061	-1.02	0.307	-0.182	0.057
Constant	0.919	0.031	30.09	0.000	0.859	0.979
$\boldsymbol{P_t^*(K_t) - P_t(K_t)}$						
LTFTR	-19.800	4.383	-4.52	0.000	-28.391	-11.209
Holiday	-1.375	4.383	-0.31	0.754	-9.966	7.216
LTFTR*Holiday	10.875	6.199	1.75	0.079	-1.274	23.024
Constant	15.092	3.099	4.87	0.000	9.017	21.166

Table 3 reveals that the treatments do not differ significantly with respect to static efficiency, which leads to the conclusion that the differences in general efficiency which we observe are routed in differences in dynamic efficiency, that is in the amount of investment undertaken / capacity installed by the TSO. Before we proceed to the discussion of potential causes for differences in dynamic efficiency, it is worth to note that Table 3 reveals that the price signal is more efficient in treatments with LTFTR given the amount of capacity which is installed. We find that in non-LTFTR treatments, the spot price is too low compared to the static optimum as defined above, while in the two treatments with LTFTR auctions the spot price is higher but overall much closer to the static optimum (though further away from the dynamic optimum).

4.2. Dynamic Efficiency

As stated above, dynamic efficiency depends on the level of investment taken by the TSO facing the incentives of the different treatments. In Section 3.2 we identified that general efficiency in the **Holiday treatment** fell somewhat short of general efficiency in the baseline treatment. The Mixed effects estimation in Table 1 indicates and the Mann-Whitney tests find that the level of investment (i.e. the installed pipeline capacity) in the Holiday treatment is indeed comparatively lower. Hence, relating back to the discussion of our motivation to include regulatory holidays in this project, the data suggests that the positive effect of a higher profit potential on investments is more than offset by the negative market power effect. That is, for our environment the TSO finds it optimal to withhold / delay investment in the Holiday treatment compared to the Baseline treatment in order to maximize its temporarily unregulated spot market income. Opposing the relatively minor (but significant) decrease in general efficiency is a significant increase in TSO profits in the Holiday treatment compared to the Baseline (or indeed all other treatments). We will discuss policy implications later, but this finding is clearly relevant in this regard.

Similar to the Holiday treatment, general efficiency in the **LTFTR treatment** falls short of general efficiency in the Baseline treatment, and similarly the cause is a lower investment level / lower dynamic efficiency (confer to Section 3.2). We have not yet finalized our analysis for the cause of this shortfall but offer the following conjecture. Recall from Section 3.2, Figure 4a in Appendix A and Table 4 in Appendix B that LTFTR prices in the LTFTR treatment are significantly lower than spot prices. In general, this indicates that no arbitrage between spot and forward markets takes place. Specifically though, in the LTFTR treatment the TSO's profit solely depends on the LTFTR price, which as indicated above, is significantly lower than the spot price. Thus we conjecture that the level of investment is – compared to the Baseline treatment - lower because of the low LTFTR price in the LTFTR treatment.

But why do we observe this low LTFTR price and the persisting difference compared to the spot price in the first place? Recall that the TSO is forced in the LTFTR treatment to sell all capacity forward. Bidding data (whose analysis we have not completed yet) in the LTFTR auctions seems to suggest that not all shippers want to hedge themselves and instead solely rely on spot market acquisition of capacity. We do however so far not have an explanation why some shippers are reluctant to hedge themselves. Another contributing factor for the persisting price difference is the observed overbidding of hedged shippers in the spot markets, which in turn raises prices as well. Please refer to Tables 5a and 5b in Appendix B for an overview.

Finally, we observe that general efficiency in the **LTFTR & Holiday treatment** is significantly lower than in all other treatments, indicating a severe negative interaction of LTFTR markets and regulatory holidays. And once more the results presented in Section 3.2 and in Section 5.1 indicate that a significantly lower level of investment causes this shortfall. Although we are as of this point unaware for the exact causes behind this result, we can rule out one particular line of argument: One could assume that the additional information on future demand gained by the TSO in the LTFTR & Holiday treatment helps it to monopolize more efficiently on residual demand. However, the results provided in Table 2 as well as the accompanying Mann-Whitney test indicate that compared to the Holiday treatment which lacks this additional information, the TSO obtains a lower profit. Hence the additional information provided by the LTFTR auctions does not help the TSO to more effectively utilize the regulatory holiday scheme.

The following section outlines policy implications and concludes.

5. Conclusion

Using economic laboratory experiments we have established that both the introduction of regulatory holidays and the introduction of LTFTR significantly affect general efficiency in the market and distribution of profits. While the introduction of regulatory holidays does slightly decrease overall efficiency in our environment, it does substantially increase TSO profits. We do believe that this distributional effect is robust towards changes in the parameterization of the experimental environment. Taking the relative minor differences in general efficiency observed into account, it is possible that in an environment which features higher demand volatility or ex-ante uncertainty about future demand than ours, regulatory holiday regulation might outperform RoR with used and useful rules, that is the positive effect of higher profit potential for the TSO as a compensation for ex-ante risk could outweigh the negative effect of increased market power. Thus, regulators should not generally discard regulatory holiday regulation as a viable regulatory alternative to more "established" regulatory schemes if high volatility of demand or high ex-ante risk of stranded assets is to be expected. Similarly, RoR regulation enhanced with LTFTR markets could perform better as well in such situations, as it at least permits the TSO for the validity period of the LTFTR to hedge itself against stranded assets.

However, our experiments established three other important findings: First, combining regulatory holidays with LTFTR severely decreases general efficiency for reasons not fully explored so far. We will continue to investigate this issue. Second, we find that LTFTR prices consistently fall short of spot prices for capacity. Again, we could so far not fully explain this issue, however a sensible policy implication from this result is that a TSO should probably not be forced to sell all pipeline capacity forward, as this eliminates the opportunity for the TSO to arbitrage between spot and LTFTR markets, which in turn could be detrimental to general efficiency. Finally, spot prices in the presence of LTFTR markets are closer to the static optimum but significantly higher than in treatments without LTFTR (and hence further away from the dynamic optimum). This can put intermittent users of the capacity spot markets who willingly or unwillingly fail to obtain LTFTR at a disadvantage compared to a non-LTFTR regulatory environment, where they would face lower spot prices.

In summary, this research project endows policy makers both with readily available insights as well as with directions for future research to be conducted. The findings that a) regulatory holidays affect profit distribution significantly in favor of the TSO and that b) RoR regulation with used and useful rules generally offers convincing results efficiency-wise even (or more precisely especially) in the absence of long-term demand information belong to the first category. The exact causes for the latter effect should however be further investigated. It also represents an insight that could arguably only be identified in the first place using laboratory experiments. Substantial research efforts should also be directed at exploring the issues of coordination of investments and compensation for externalities, both of which were not covered with this report.

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Appendix A

Figure 1: Pipeline Capacity

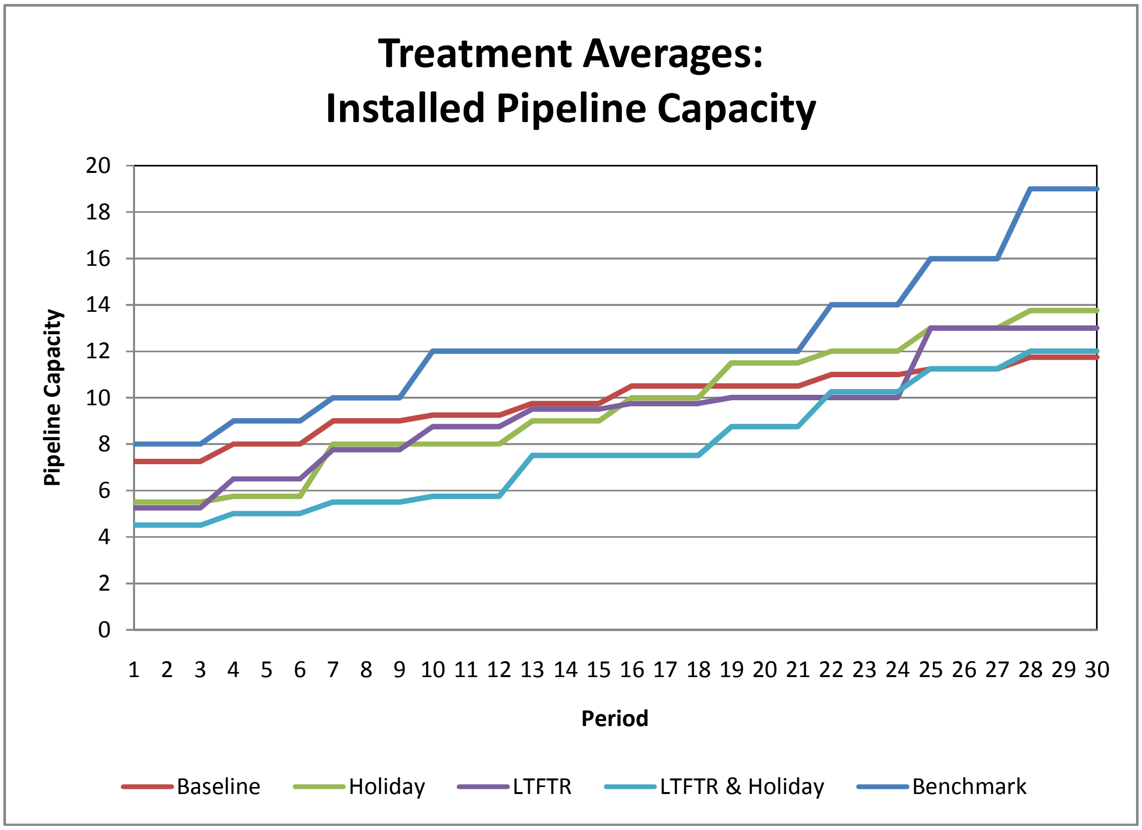


Figure 2: Capacity Spot Price

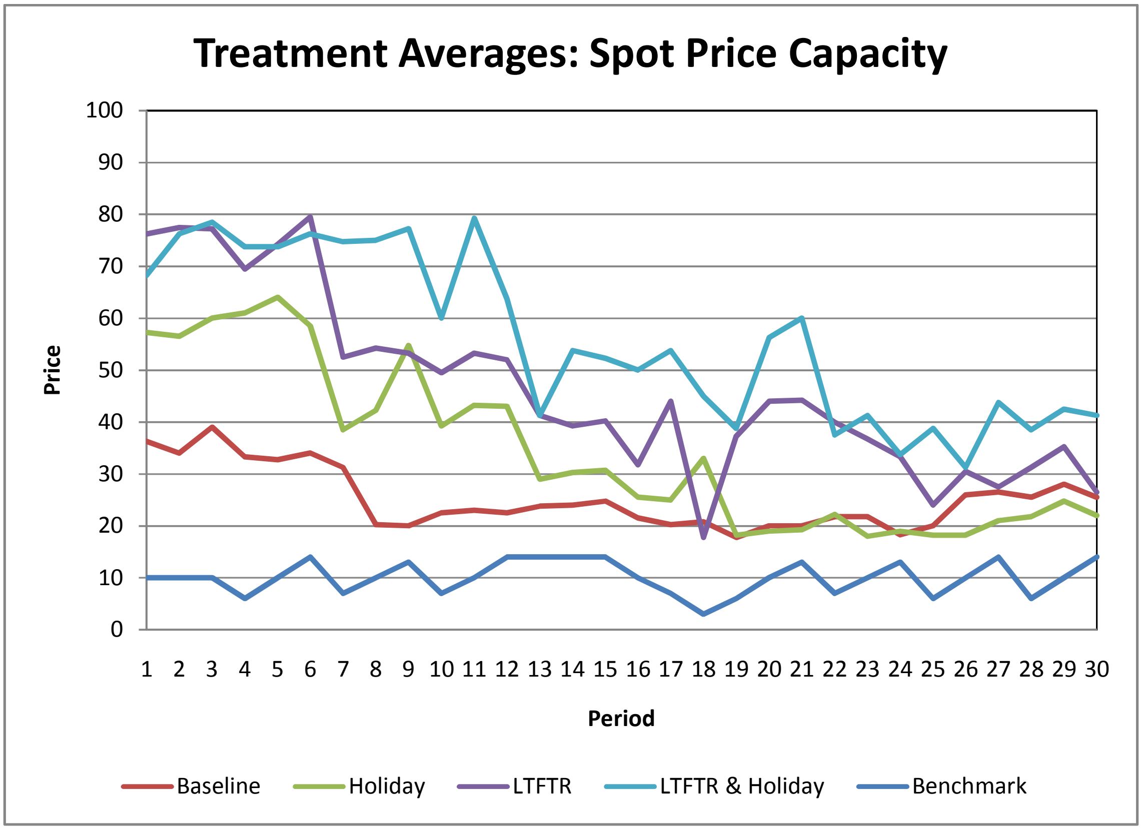


Figure 3: General Efficiency

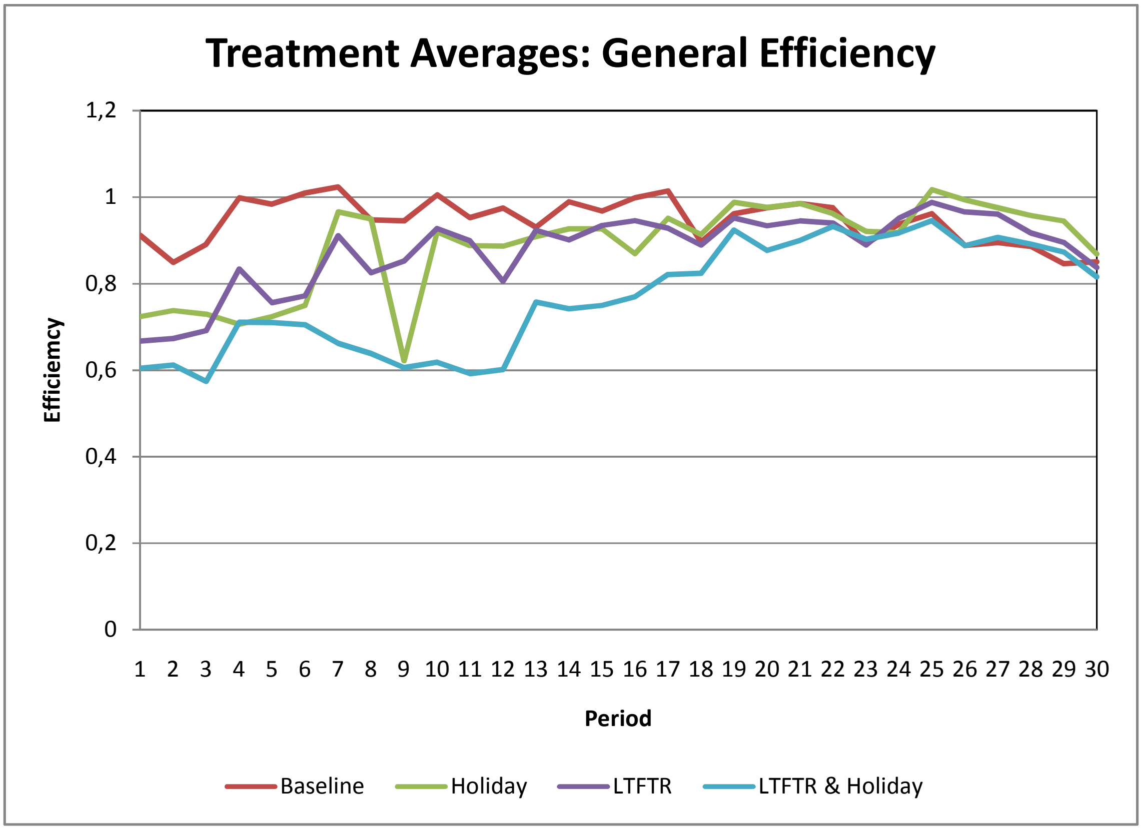


Figure 4a: Capacity Spot Price and LTFTR Price in the LTFTR Treatment

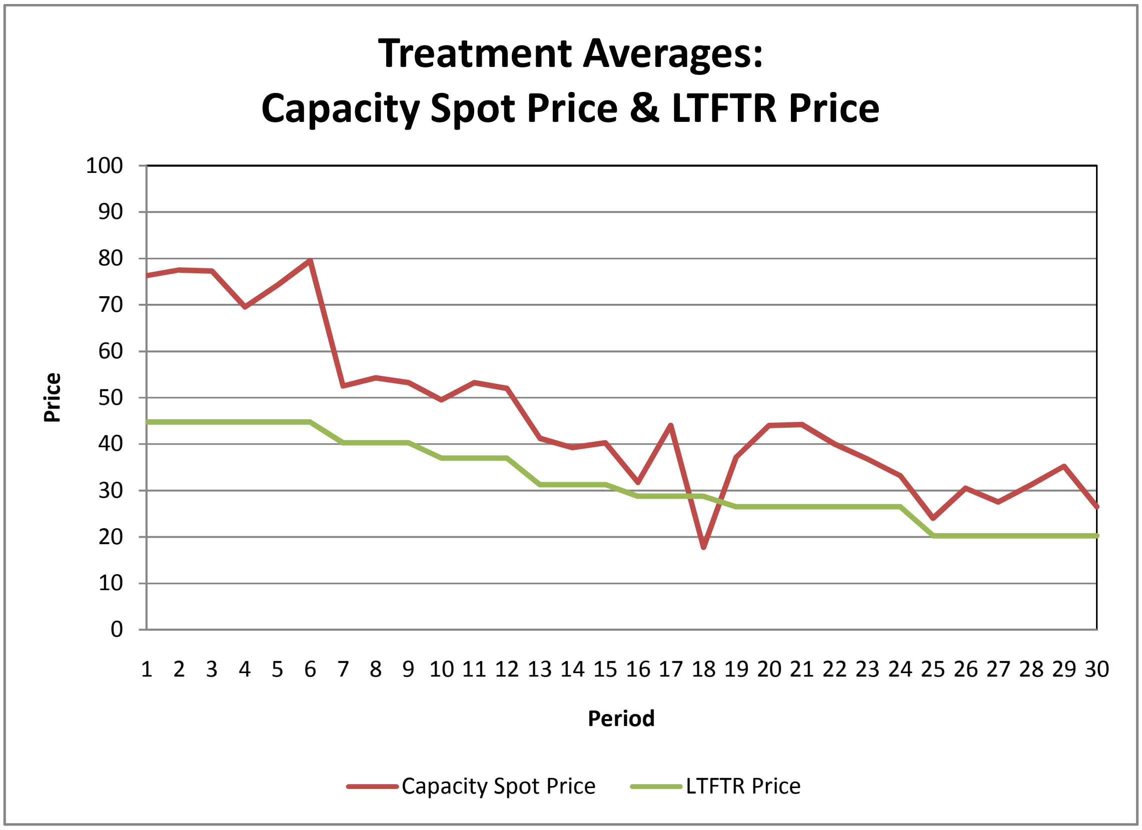
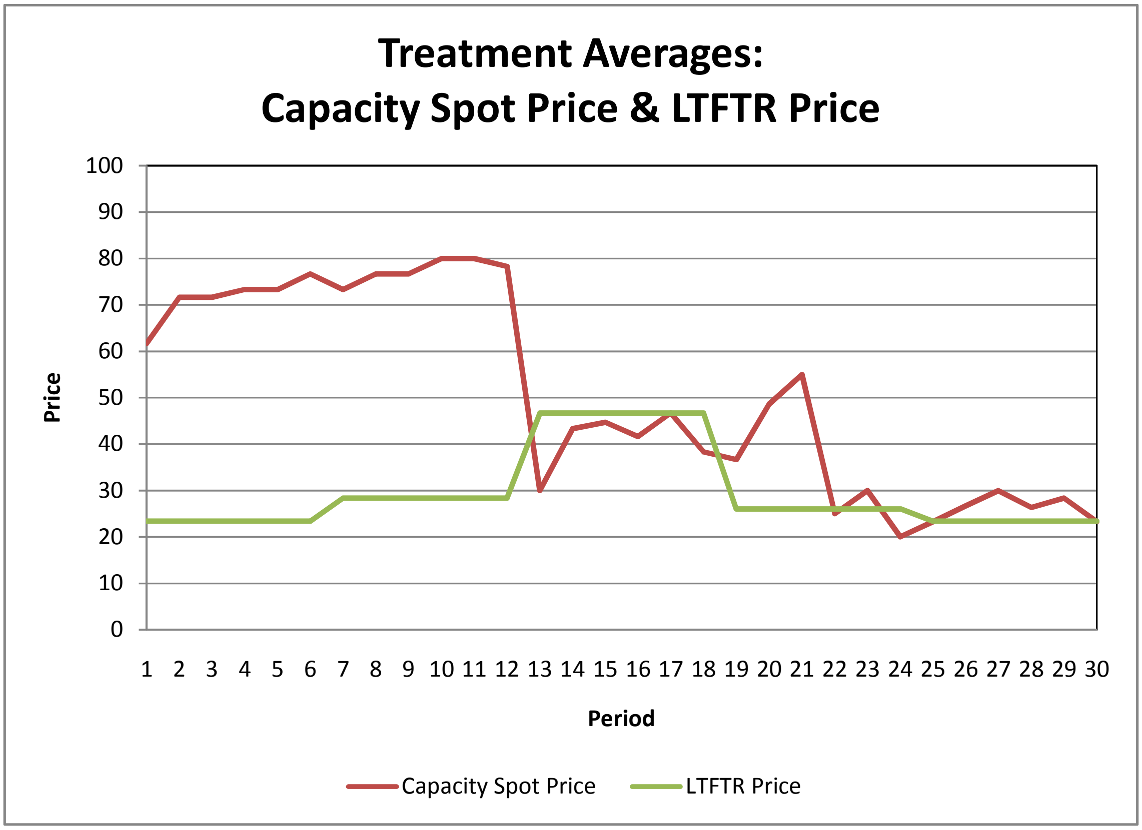


Figure 4b: Capacity Spot Price and LTFTR Price in the LTFTR & Holiday Treatment



Appendix B

Table 4: **t-test Difference between Spot Prices and LTFTR prices**

	Obs	Mean	Std. Err.	Std. Dev	95% Conf. Interval	
LTFTR	120	14.433	2.232	24.453	10.013	18.853
LTFTR & Holiday	120	17.025	2.585	28.320	11.906	22.144

Table 5a: **t-tests on the Difference between the n-th Highest Capacity Valuation and the n-th highest Spot Bid in the LTFTR treatment**

	Obs	Mean	Std. Err.	Std. Dev	95% Conf. Interval	
1st Valuation – 1st Spot Bid						
Not Hedged	54	12.630	4.418	32.469	3.767	21.492
Hedged	426	-13.857	1.586	32.729	-16.974	-10.740
2nd Valuation – 2nd Spot Bid						
Not Hedged	114	19.325	3.230	34.482	12.926	25.723
Hedged	366	-14.773	1.847	35.336	-18.405	-11.141
3rd Valuation – 3rd Spot Bid						
Not Hedged	297	2.199	0.495	8.533	1.224	3.173
Hedged	183	-35.699	3.777	51.092	-43.151	-28.247
4th Valuation – 4th Spot Bid						
Not Hedged	378	2.862	0.573	11.139	1.736	3.989
Hedged	102	-35.059	5.013	50.625	-45.003	-25.115
5th Valuation – 5th Spot Bid						
Not Hedged	450	-0.751	0.346	7.341	-1.431	-0.071
Hedged	30	-28.567	7.240	39.653	-43.373	-13.760
6th Valuation – 6th Spot Bid						
Not Hedged	465	-0.972	0.349	7.522	-1.658	-0.287
Hedged	15	-14.400	8.100	31.373	-31.773	2.974

Table 5b: **t-tests on the Difference between the n-th Highest Capacity Valuation and the n-th highest Spot Bid in the LTFTR & Holiday treatment**

	Obs	Mean	Std. Err.	Std. Dev	95% Conf. Interval	
1st Valuation – 1st Spot Bid						
Not Hedged	150	12.713	2.374	29.081	8.021	17.405
Hedged	330	1.106	1.616	29.349	-2.072	4.284
2nd Valuation – 2nd Spot Bid						
Not Hedged	192	13.396	1.952	27.050	9.545	17.246
Hedged	288	-3.931	1.833	31.109	-7.539	-0.323
3rd Valuation – 3rd Spot Bid						
Not Hedged	390	6.374	0.511	10.100	5.369	7.380
Hedged	90	-30.889	4.858	46.086	-40.541	-21.236
4th Valuation – 4th Spot Bid						
Not Hedged	426	4.049	0.385	7.953	3.292	4.807
Hedged	54	-37.981	6.811	50.051	-51.643	-24.320
5th Valuation – 5th Spot Bid						
Not Hedged	450	0.238	0.130	2.756	-0.018	0.493
Hedged	30	-61.433	11.163	61.145	-84.265	-38.601
6th Valuation – 6th Spot Bid						
Not Hedged	462	0.145	0.132	2.839	-0.115	0.405
Hedged	18	-61.111	15.611	66.234	-94.048	-28.174

Appendix C

The Linear Aggregate Demand function for capacity is specified as:

$$D_t = a - \frac{2b}{g_t} q_t$$

Aggregate Shipper Valuation for capacity is thus given by:

$$V_t = aq_t - bg_t \left(\frac{q_t}{g_t}\right)^2 = aq_t - \frac{b}{g_t} q_t^2$$

Aggregate increase in Shipper Valuation due to commitment to must serve demand:

$$cx_t$$

Aggregate commitment costs:

$$dx_t$$

Costs for sustaining the pipeline:

$$eK_t$$

The Social Planner's objective function is thus given by:

$$\max_{q_t, x_t, I_t, K_t} \sum_{t=1}^{30} (V_t + (c - d)x_t - eK_t)$$

The constraints are:

$K_0 = 4$ — Initial Pipeline Capacity is equal to 4 units

$$K_t = K_{t-1} + I_t$$

$0 \leq I_t \leq 5$ — Maximum Expansion in Investment period is 5 units
→Pipeline capacity can never be reduced

$I_t = 0 \forall t \neq \{1,4,7,10,13,16,19,22,25,28\}$ — Expansion of pipeline capacity only possible every 3rd period

$q_t \leq K_t$ — The Lagrange-multiplier of this constraint represents the optimal spot price

$x_t \leq \min \; \{q_t, 8\}$ — Maximum total amount of must serve capacity to which the shippers can commit is 8 units

The optimization program knows all parameters and no integer optimization requirement exists (in the actual experiment, pipeline capacity can only be increased by integers and shippers must submit bids which are multiples of 1 or zero).

Appendix D

Illustration 1a: **Sequence of Actions during a six period block in treatments without LTFTR markets**

	Six Period Block					
	1st Period	2nd Period	3rd Period	4th Period	5th Period	6th Period
Shippers learn about their individual demand for Periods 1 – 6	X					
Shipper decide on whether to commit to must serve obligations	X					
TSO decides on pipeline capacity expansion	X			X		
Capacity spot auction is conducted	X	X	X	X	X	X

Illustration 1b: **Sequence of Actions during a six period block in treatments with LTFTR markets**

	Six Period Block					
	1st Period	2nd Period	3rd Period	4th Period	5th Period	6th Period
Shippers learn about their individual demand for Periods 1 – 6	X					
LTFTR Auction is conducted	X			X*		
Shipper decide on whether to commit to must serve obligations	X					
TSO decides on pipeline capacity expansion	X			X		
Capacity spot auction is conducted	X	X	X	X	X	X

* Only in the “LTFTR treatment”: If the TSO decides to expand pipeline capacity, it is required to issue an equivalent number of LTFTR for that expansion in the “LTFTR” treatment. There is no such obligation in the “Holiday & LTFTR” treatment.