Incentives for Vertically Integrated Firms in the Natural Gas and Electricity Markets to Manipulate Prices

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ABSTRACT

This paper examines the potential for vertically integrated firms that own assets in both the natural gas and electricity markets to manipulate natural gas and electricity prices through the withholding of natural gas pipeline capacity. An integrated firm theoretically could increase the price it receives in the electricity market by withholding pipeline capacity to the wholesale natural gas market, thereby reducing wholesale supply of natural gas and potentially increasing generation costs for electricity through higher natural gas prices. A key criteria in assessing whether an integrated firm's allocation of pipeline capacity between the wholesale and retail markets constitutes manipulation relates to whether the allocation is profit maximizing on a stand-alone basis, i.e., the allocation maximizes the firm's profits in the natural gas market without considering its profits in the electricity market. I develop a theoretical model that examines the incentives to allocate pipeline capacity to the wholesale natural gas market, which supplies the power generation sector, and the retail natural gas market. I find that an integrated firm may choose to allocate more pipeline capacity to the retail market than the wholesale market in order to reduce the probability of paying fines from failing to adequately meet retail demand, to increase its profits in the wholesale natural gas market, or to increase its profits in the electricity market. In order to prove a manipulation has occurred, it must be shown that the last case is true and the first two cases had little effect on the allocation decision.

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In 2019, the EIA projected that natural gas combined-cycle units were likely to be the marginal supply for electricity generation in the U.S. through 2050 (EIA, 2019). While the overall supply of natural gas has expanded as a result of the "Shale Gas Revolution", limited pipeline capacity for delivering that supply to some regions has resulted in sometimes fierce competition between different potential customers. These customers can typically be grouped into three different categories: retail (residential and commercial), industrial and electric. Historically, retail sector demand for residential heating dominated natural gas demand, particularly in northern locales where cold weather outbreaks lead to strong winter peaks in demand. These retail customers tend to be supplied by utilities, which purchase natural gas for their customers through the wholesale market. Demand for industrial use and electricity generation, on the other hand, are often supplied directly from the wholesale markets.

The key issue I examine in this paper is the possibility of vertically integrated firms that own midstream and downstream natural gas assets, as well as gas-fired electric generation, ma-

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nipulating gas supplies to increase electricity prices and thus increase overall profits. My point of departure is a recent study by the Environmental Defense Fund (Marks et al., 2017), which claims that two natural gas local distribution companies (LDCs) in New England, whose parent entities also own electricity generators, purposely withheld pipeline capacity from wholesale purchasers to increase natural gas prices and hence increase profits for their electricity generators. They calculate that the claimed action imposed losses on the order of $U.S. 3 billion on electricity and natural gas ratepayers. Their study prompted an investigation by the Federal Energy Regulatory Commission (FERC, 2018), presumably into whether the two accused firms' scheduling practices were orchestrated to manipulate the market in withholding natural gas pipeline capacity to the wholesale market in New England from 2013-2017. The FERC's investigation found no evidence of anticompetitive withholding of natural gas pipeline capacity by either company.

While FERC ultimately determined that there was no anticompetitive withholding by the two LDCs in the New England natural gas market from 2013-2017, the Environmental Defense Fund study and subsequent FERC investigation raise interesting questions of a more general nature regarding the increasingly interconnected electricity and natural gas markets in every geographic region. In particular, under what conditions would vertically integrated firms be motivated to withhold pipeline capacity from the wholesale market to artificially increase the price of natural gas, potentially increasing generation costs for electricity, and consequently increasing the profits they earn in the electricity market? Furthermore, if a vertically integrated firm allocates more pipeline capacity to the retail market than it ultimately ends up using, could such behavior be viewed as an attempt to withhold pipeline capacity from the wholesale natural gas market and manipulate electricity prices?[1]

This paper provides an analytical framework that allows one to assess the potential for vertically integrated firms to profit from withholding natural gas pipeline capacity. It shows that firms can choose to allocate more pipeline capacity to the retail market than the wholesale market for a variety of reasons. In particular, a firm may choose to allocate more pipeline capacity for retail gas, holding all else equal, if doing so will 1) reduce the likelihood of facing retail market penalties, 2) increase its profits in the wholesale natural gas market, or 3) increase profits earned in the electricity sector. Importantly, the first two reasons do not constitute market manipulation because they each serve a stand-alone legitimate business purpose: the first is the avoidance of penalties and the second is the traditional exercise of market power.[2] The third reason, however, could be considered a cross-market manipulation. Market manipulations are generally defined to occur when an economic decision is not profit-maximizing on a stand-alone basis, but rather undertaken to increase profits in unrelated markets. Recently, Ledgerwood et al. (2019) defined market manipulation to be an action that "injects information into the market to cause demand or supply to 'falsely' or 'artificially' deviate from their economic fundamentals."

This analysis will show that integrated firms may be motivated by legitimate and/or manipulative reasons when determining their allocation of pipeline capacity between the wholesale and

1. Natural gas LDCs serve their customers by procuring and distributing natural gas. This generally includes transporting gas from supply areas using long-haul interstate pipelines. To do this, the LDCs have capacity contracts on these pipelines and submit nominations to utilize this pipeline capacity. If the LDCs anticipate having excess capacity, the LDCs could either 1) sell gas that they transport using their contracted pipeline capacity to other wholesale buyers (e.g., to power plants), 2) release this capacity to the extent they do not utilize it, or, 3) not nominate for that capacity thereby allowing others to utilize said capacity on a non-firm basis.

2. In this paper, I assume that wholesale sales of natural gas and natural gas pipeline capacity constitute the same market. If they belong to the same market, allocating less pipeline capacity for wholesale natural gas can be seen as an exercise of market power. If, however, one assumed that the two markets were separate from one another, it could be argued that allocating less pipeline capacity to the wholesale market could be a market manipulation. I do not address this herein.

retail natural gas markets. It finds that in order to suggest a manipulation has occurred, it must be shown that penalties and profits in the gas markets have little effect on the firm's allocation mechanism and that it is instead guided by profits in wholesale electricity markets. Furthermore, it finds that it is easier to detect manipulative behavior when pipeline constraints are not binding, as there are less confounding factors that arise when there is sufficient pipeline capacity. It is important to note that for the previous statement to be true, there must be the pipeline equivalent of a "pivotal supplier" with sufficient contracted capacity such that its supply of pipeline capacity is necessary to clear the market. The pivotal supplier could theoretically reduce pipeline supply and artificially make the constraint binding, thus rendering a potential manipulation profitable. More generally, the framework provides a basis to understand the decision to allocate supply, which is scarce as a result of limited pipeline capacity between the wholesale and retail natural gas markets. The results of this paper should aid policymakers in formulating regulations to increase efficient market outcomes by providing a theoretical understanding of the current incentives in the natural gas markets.

1. RELEVANT LITERATURE

This study was inspired by the FERC's recent investigation into the alleged market manipulations of natural gas prices in New England and the FERC's decision to drop its investigation of anticompetitive withholding in the natural gas capacity market. The FERC's investigation was motivated by Marks et al. (2017), which claimed two firms scheduled more gas than they actually delivered, consequently reducing pipeline capacity and creating price spikes. Marks et al. (2017) claim that state regulations, which require firms to repatriate the majority of their profits earned in the wholesale market back to ratepayers, encourage integrated firms to withhold pipeline capacity. They analyze panel data of pipeline scheduling and find that firms operating in states with higher pass-through rates tend to schedule more natural gas than they actually sell. Marks et al. (2017) construct a counterfactual scenario where they find natural gas and electricity prices were 38% and 20% higher, respectively, due to the alleged capacity withholding. In response, Levitan and Associates, Inc. (2018) argued that the contested behavior could be explained primarily by demand forecasting errors and penalties incurred when an LDC fails to reserve sufficient space for its retail demand.

Apart from the specifics of the New England case, there is an extensive and growing literature on vertical integration and its effects on competition. Riordan (2005) provides a comprehensive review of the field, grouping and categorizing the literature by unifying themes. Riordan (2005) discusses the importance of market power assumptions in the upstream and downstream markets when determining the effects of vertical integration on consumer welfare. Hart and Tirole (1990) develop a theoretical model to examine vertical integration and how it affects competition both in upstream and downstream markets, and use their model to assess some well-known vertical mergers. Rey and Tirole (2007) provide an overview of market foreclosures, which occur when a firm restricts output by using its market power in another market, and their impact on consumer welfare, as well as potential remedies.

An important concept considered in the literature described above is what is known as raising rivals' costs, which is discussed in Salop and Scheffman (1983). This occurs when an upstream firm increases the prices of production inputs to the rivals of their downstream counterparts, thus increasing market prices and profits for their downstream counterparts. With respect to the energy markets, Hastings and Gilbert (2005) examined the West Coast wholesale gasoline market from 1996-1998, finding that mergers between retail firms and refineries in the gasoline market led to higher wholesale prices of gasoline. In a context more like the New England case outlined above, Barquin et al. (2006) discuss the potential costs for consumers from allowing a merger to occur between a prominent Spanish electricity producer and a natural gas distributor, and illustrate the potential market manipulations that could occur with such a merger.

Hunger (2003) also examines the incentives to manipulate prices when natural gas and electric utilities merge. He argues that the elasticity of supply in the downstream market, as well as the amount of inframarginal capacity in the electricity market held by the vertically integrated firm, are crucial in understanding a merged firm's incentive to manipulate prices. If the conditions outlined in Hunger (2003) aren't met, the author argues the merged firms have no incentives to manipulate market prices and should thus not be accused of intentionally doing so. The model that I develop corroborates and formalizes some of the insights from Hunger (2003).

2. REGULATION OF LDCS

An LDC's decision to allocate limited natural gas pipeline supply between the wholesale and retail markets will depend critically upon the regulatory setting and physical restrictions the LDC faces. In particular, an LDC's supply decisions will be affected by its forecasts of retail demand, the type of pipeline service it purchases, the profitability of releasing its capacity, and the flexibility and timing with which it can nominate its gas flows on the pipeline. This section will address these features of the regulatory setting in turn. It should be noted that these regulations tend to be governed at the state level and the following section only provides a general description of common regulatory features.

2.1 Uncertainty of Demand

Most natural gas customers, apart from some large industrial, commercial and electricity generators, receive their supply from the low pressure distribution network operated by their LDC. The LDCs are natural monopolies due to the high costs of establishing a network of pipelines to reach end-users. Consequently, LDCs tend to be heavily regulated, generally at the state level. Regulatory agencies determine the rates LDCs can charge their retail customers in order to allow them to recover their costs. LDCs are expected to reliably supply their firm retail customers, and are sometimes referred to as the "suppliers of last resort".

Pipeline capacity must be nominated at specific times in the day, and the last scheduling period typically occurs before the end of the "gas day" (usually measured by a 24 hour period starting from 9 am CST of each day). Throughout the "gas day", intraday capacity is traded at specified times. In other words, the structure of the scheduling periods requires that supply be determined prior to realized demand. The amount of pipeline space that an LDC will reserve for its firm customers will thus depend on forecasted demand, which introduces an element of risk, especially during times of volatile demand.

2.2 Types of Pipeline Service

Pipelines generally offer services in both primary and secondary markets (FERC, 2015). In the primary market, shippers can elect to purchase firm or interruptible service. With firm service, the shipper has a right to its contracted space at all times. The shipper must nominate its required space for natural gas each day and a pipeline may sell any unused capacity on the secondary market. Nevertheless, contracts for firm service typically include a penalty for under-utilization of the nominated capacity.

A subset of firm service that a pipeline may offer is known as no-notice service. This type of service reserves a contracted capacity for the shipper and allows the shipper to adjust its nominations throughout the gas day without penalty. Generally, this type of service is reserved by LDCs, which face uncertain demand. Both shippers with no-notice and firm service can elect to sell their capacity on the secondary market; once the space is sold on the secondary market, however, the primary holder of the service no longer has a right to this space during the contracted period. Thus, it is risky for an LDC to sell its no-notice service when there is some positive probability that demand will increase by an amount higher than expected, as it cannot simply stop flowing natural gas to its customers. Since no-notice service gives the shipper additional options, it is sold at a premium to firm service.

Shippers can also purchase interruptible service, which allocates space to the purchaser only if there is available capacity on the pipeline. Generally, interruptible service can be bumped during earlier nomination cycles but not during the last intraday cycle. This means that a firm shipper may lose its contracted capacity if it does not nominate said capacity early enough, posing a risk to the firm shipper if it does not nominate enough pipeline capacity to fulfill its obligations. Industrial consumers tend to purchase this type of service (EIA, 2016) as it is discounted relative to the other types of service and they often have opportunities to reduce their use of natural gas for short periods of time at relatively low cost. Electricity generators may also purchase this type of service, especially when they can make up for shortfalls in natural gas generation by using alternative fuels or technologies. They can also elect to purchase unused capacity on the secondary market from LDCs and gas marketers. This may be explained by the fact that the demand for electricity tends to be counter-cyclical to demand for natural gas (i.e., high heating loads correspond with low electricity usage and vice versa). Consequently, an LDC's nomination of its firm service and no-notice capacity will affect the cost of generation in the electricity sector. During periods of high demand and scarce pipeline capacity, an LDC's increased use of its pipeline capacity will restrict the ability of electricity generators to procure natural gas.

2.3 Scheduling of Nominations

Generally, shippers must adhere to a strict schedule for reserving space on a pipeline. Different pipelines have different rules for scheduling, but they all follow a similar pattern. A shipper must provide its first nomination for pipeline space during a period known as the timely cycle, which generally occurs one day prior to the "gas day" (Smith, 2015). Following the timely cycle, shippers can usually update their nominations during an evening cycle, which generally occurs the evening before the "gas day". Finally, there are a few intra-day nomination periods where shippers can adjust their nominations at various times during the gas day (FERC, 2015). No-notice contract holders have the advantage of not being penalized for inaccurately nominating their gas flows, as long as they do not exceed their no-notice capacity. If they cause imbalances on the pipeline above their contracted capacity during periods of high demand, however, they will be penalized, typically by some multiple of the delivery point ("citygate") price.

3. POSSIBILITY FOR MARKET MANIPULATION THROUGH VERTICAL INTEGRATION

There are various ways an agent can profit from manipulating the availability of natural gas pipeline capacity. Most generally, any asset that has a value that is tied to the price of natural gas can benefit from an increase in the price of natural gas.[3] In the following analysis, however, I focus directly on the electricity market, although the results of this paper would hold more generally to these other assets.[4]

If a parent company maintains a presence as an inframarginal supplier in the electric generating sector and chooses to manipulate the price of natural gas, it theoretically could increase its profits by withholding natural gas pipeline capacity in the wholesale natural gas market to reduce the supply of natural gas. This would increase the price of natural gas, holding all else equal, and would change the shape of the electricity market's supply curve. If natural gas was an inframarginal or marginal fuel in the electricity market before the increase in its price, the change in the price of natural gas could result in a higher market clearing price in the electricity market. For this strategy to be profitable, however, the vertically integrated firm must possess inframarginal generation capacity after the change in the gas price has occurred and its costs must increase by less than the increase in the price of gas. If the firm remains a marginal supplier (or an extramarginal supplier) before and after any price increase, or if its costs increase sufficiently so as to negate the increased revenues from the higher electricity price, it will not profit from increasing the market price for electricity.[5]

An integrated firm that owns inframarginal generators therefore could create profits from the electricity market by restricting pipeline capacity, thus increasing the price of natural gas so that a higher cost generator becomes the marginal supplier. If the gains from the electricity market are high enough, this could incentivize the integrated firm to commit a market manipulation. This is the theory that was espoused by Marks et al. (2017).

4. MODELING A VERTICALLY INTEGRATED FIRM'S INCENTIVE TO MANIPULATE NATURAL GAS PRICES

4.1 Defining the Model

In order to understand the effects of allocating less natural gas pipeline capacity to the wholesale market and the incentives to do so, I develop a theoretical model. I do find potential support for the Marks et al. (2017) contention that withholding can be manipulative in a narrow range of circumstances, but I also find that one reason to reduce pipeline supply to the wholesale market stems from the desire to avoid large penalties from reserving insufficient pipeline space to supply retail demand.

As described in Section 2, LDC utilities must often schedule their nominations in advance of realized demand. This becomes problematic during periods of extreme cold, when demand for heating is high and difficult to predict. During high demand periods, shippers are forced to pay large penalties[6] if they withdraw more natural gas from the pipeline than they schedule. No-notice service then becomes very valuable to LDCs as it allows them to change their shipping volumes without

3. While this analysis uses the electricity market as the primary area of focus when investigating the impacts and possibility of natural gas price manipulation, there are various classes of assets that can profit from increases in natural gas prices. For instance, any financial swap that is tied to the price of electricity would similarly benefit in the scenarios discussed in this paper.

4. It is important to note that such outcomes occur due to the allocation mechanism and may occur absent manipulative behavior.

5. It also will not profit if its electric generators are subject to regulated rates of return.

6. On the Algonquin pipeline, the relevant pipeline in the FERC investigation, shippers were charged approximately three times the Algonquin citygate price if they caused imbalances on the pipeline during periods of high demand (Levitan and Associates, Inc. 2018).

incurring penalties. Consequently, LDCs are unlikely to sell no-notice or firm space to third party shippers during times of scarce capacity as this decreases their ability to respond to unexpected demand shocks.

Formally, I consider how an LDC would choose to maximize expected profits, subject to the physical and contractual constraints described in Section 2. I start by defining the profits it would receive in each sector and then present a model that explores how a vertically integrated LDC would allocate its no-notice service between the retail and wholesale markets to maximize its expected profits.

In the electricity market, the vertically integrated firm's profits will consist of the difference between the market price of electricity and its per unit generation cost times the amount of electricity it generates. I define s_E to be the firm's supply of electricity and d_E to be the market demand for electricity, respectively. I assume demand is a function of the price of electricity, p_E, and an exogenous shock, D_E, that has a probability density function h with support $[0, \bar{D}_E]$. The price of electricity, p_E, is determined in the electricity market to equate demand to the available market supply. Since generation costs may depend on the wholesale price of natural gas (if natural gas is used to generate electricity), I allow the reduced form solution of the price of electricity to be a function of the wholesale price of natural gas, p_W, as well as the demand and market supply of electricity. Further, for similar purposes, I allow generation costs, notated as c_E, to be a function of p_W. Thus, the expected profits earned in the electricity sector are:

$$E(\Pi_E) = \int_0^{\bar{D}_E} [s_E(p_E - c_E)] h(D_E) dD_E \tag{1}$$

In the wholesale market, I assume the LDC earns its wholesale profits through sales of its natural gas pipeline capacity. Since most LDCs' profits from the wholesale natural gas market are regulated and repatriated back to ratepayers, I allow the wholesale market profits to be scaled by the parameter δ; it must repatriate $(1-\delta)$ of its profits to its ratepayers. I define S_W and d_W to be the firm's supply of pipeline capacity and the wholesale market demand of pipeline capacity, respectively. I assume demand is a function of the wholesale price of natural gas, p_W, and an exogenous shock, D_W, that has a probability density function g with support $[0, \bar{D}_W]$. The price of wholesale natural gas pipeline capacity, p_W, balances demand to the available market supply and is determined in the wholesale market. I thus assume the reduced form solution of the price of natural gas pipeline capacity in the wholesale market is a function of d_W and S_W. I allow S_W to be the decision variable. Finally, I define the cost of supplying natural gas pipeline capacity to the wholesale market as c_W, which I assume has a constant marginal cost. The LDC's expected profits in the wholesale capacity market are then represented by:

$$E(\Pi_W) = \int_0^{\bar{D}_W} [\delta(S_W(p_W - c_W))] g(D_W) dD_W \tag{2}$$

In the retail natural gas market, I assume profits are regulated to allow the LDC to recover its costs. I denote this rate as η and assume it is exogenous. I define s_R and d_R to be the firm's supply of retail natural gas and the market demand for retail natural gas, respectively. I assume demand is a function of the retail price of natural gas, p_R, and an exogenous shock, D_R, that has a probability density function f with support $[0, \bar{D}_R]$. In the model I allow the price of retail natural gas, p_R, to be the reduced form solution of price that is determined in the retail market to equate demand to the available supply. I define S_R to be the no-notice space reserved for retail supply. In the retail sector s_R and S_R are not necessarily equivalent. If the LDC does not reserve sufficient space on the pipeline to supply d_R, such that $d_R > S_R$, and consequently needs to use non-contracted pipeline space to fulfill demand, it will then incur a penalty of $\alpha \geq 1$ times the citygate price of natural gas, p_C. The expected profits in the retail market are then defined as:

$$E(\Pi_R) = \int_0^{\bar{D}_R} \eta s_R f(D_R) dD_R - \int_{S_R}^{\bar{D}_R} \alpha (d_R - S_R) p_C f(D_R) dD_R \tag{3}$$

Finally, $\bar{S}$ represents the amount of interruptible service the utility has already committed to serve to the wholesale market.[7] S_{Max} represents the firm's no-notice capacity on the pipeline.[8] When the LDC does not reserve sufficient space for retail demand and needs to use additional, non-scheduled pipeline capacity to fulfill demand, it may need to purchase pipeline capacity greater than S_{Max} and incur a penalty for doing so.

The LDC's objective function is then the sum of its expected profits earned in the three sectors, subject to the constraints described above. The LDC must choose the amount of pipeline capacity to reserve for the retail market, S_R, and for the wholesale market, S_W, to maximize its expected profits. Equation (4) below formalizes the firm's expected profits and constraints.

$$E(\Pi) = \int_0^{\bar{D}_E} \int_0^{\bar{D}_W} \int_0^{\bar{D}_R} [s_E(p_E - c_E) + \delta S_W(p_W - c_W) + \eta s_R] f(D_R) g(D_W) h(D_E) dD_R dD_W dD_E$$

$$-\int_{S_R}^{\bar{D}_R} \alpha (d_R - S_R) p_C f(D_R) dD_R$$

such that:

$$S_R + S_W \leq S_{Max}$$

and

$$S_W \geq \bar{S}$$

and

$$s_R = d_R \tag{4}$$

I make the following assumptions on the costs and prices in the model:

$$\frac{\partial p_E}{\partial S_W} \leq 0 \tag{5}$$

$$\frac{\partial c_E}{\partial S_W} \leq 0 \tag{6}$$

$$\frac{\partial p_W}{\partial S_W} \leq 0 \tag{7}$$

$$\frac{\partial p_R}{\partial S_R} \leq 0 \tag{8}$$

which assume that the price of electricity, the cost of generating electricity, the wholesale price of natural gas pipeline capacity, and the retail price of natural gas all decrease when the quantity of pipeline capacity supplied to their respective markets increase.

7. I could also allow $\bar{S}$ to be endogenous. This would require a dynamic model and should be considered in subsequent iterations of the model.

8. In this analysis, S_{Max} is taken as given. An interesting extension of the model would include treating S_{Max} as a decision variable.

4.2 The Optimal Supply of Natural Gas Pipeline Capacity to the Wholesale Market

I first start by examining a firm's optimal supply of pipeline capacity to the wholesale natural gas market to understand what motivates its supply decision and how these factors affect the decision to supply the wholesale natural gas market. This will aid in understanding, when, and if, a firm is attempting to manipulate the market. In this section, I examine the optimal supply of natural gas pipeline capacity to the wholesale market, both when pipeline capacity is scarce and plentiful. In the following section, I will evaluate when an LDC would choose to only meet its minimal supply obligations to the wholesale natural gas market.

When determining the optimal pipeline supply to both markets, I will not consider the case where the interruptible service constraint binds, as this will produce the trivial solution that $S_W = \overline{S}$. I will thus consider two cases: (1) the LDC is constrained in its supply decisions so that it uses its total pipeline capacity ($S_{Max} = S_W + S_R$) and (2) the LDC does not find it profitable to use its total capacity ($S_{Max} > S_W + S_R$).

Case 1: $S_{Max} = S_W + S_R$

Case 1 considers how an LDC will allocate its pipeline capacity between the wholesale and retail sectors, assuming it is profitable to supply more than $\overline{S}$ to the wholesale market. The firm will provide more natural gas capacity to the sector that provides the greatest expected profits (including potential penalties). In this case, the LDC solves the following problem:

$$Max_{S_W,S_R} E[s_E(p_E - c_E) + \delta S_W(p_W - c_W) + \eta d_R - \alpha(d_R - S_R)p_C] + \lambda(S_{Max} - S_R - S_W) \quad (9)$$

The first order conditions from Equation (9) lead to the following solution for the optimal supply of wholesale natural gas:

$$S_W = \frac{E[-s_E(\frac{\partial p_E}{\partial S_W} - \frac{\partial c_E}{\partial S_W}) - \frac{\partial s_E}{\partial p_E}\frac{\partial p_E}{\partial S_W}(p_E - c_E) - \delta(p_W - c_W) + \alpha p_C]}{E[\delta \frac{\partial p_W}{\partial S_W}]} \quad (10)$$

Equation (10) suggests that the optimal supply of capacity to the wholesale market, when pipeline capacity is binding, depends on the marginal profits earned in the electric market; the marginal penalty of failing to adequately supply the retail market; profits in the wholesale capacity market; the value of δ; as well as the price responsiveness to supply in the wholesale capacity market. Importantly, I notice that the supply to the wholesale market will decrease as the penalty for under-supplying retail demand increases; when marginal profits in the electric sector increase by decreasing the supply of wholesale natural gas;[9] and when profits derived in the wholesale natural gas market decrease (possibly through a lower value of δ), holding all else equal. This highlights the fact that there are multiple reasons an LDC might choose to supply a lower amount of pipeline capacity to the wholesale market and it is imprudent to immediately assume an LDC is attempting to influence natural gas prices for its own gain. While it is in the realm of possibility that a vertically

9. Assuming $s_E(\frac{\partial p_E}{\partial S_W} - \frac{\partial c_E}{\partial S_W}) + \frac{\partial s_E}{\partial p_E}\frac{\partial p_E}{\partial S_W}(p_E - c_E) < 0$.

integrated LDC sells less pipeline capacity to the wholesale market in order to increase profits in the electric sector, I have shown that it is not the only reason.

Case 2: $S_{Max} > S_W + S_R$

In this case, the LDC is not constrained by its pipeline capacity. It thus solves the following problem:

$$Max_{S_W,S_R} E[s_E(p_E - c_E) + \delta S_W(p_W - c_W) + \eta d_R - \alpha(d_R - S_R)p_C] \tag{11}$$

and chooses to supply:

$$S_W = \frac{E[-s_E(\frac{\partial p_E}{\partial S_W} - \frac{\partial c_E}{\partial S_W}) - \frac{\partial s_E}{\partial p_E}\frac{\partial p_E}{\partial S_W}(p_E - c_E) - \delta(p_W - c_W)]}{E[\delta \frac{\partial p_W}{\partial S_W}]} \tag{12}$$

When capacity constraints are not binding, an LDC's supply of natural gas capacity to the wholesale market is negatively related to its marginal profits from sales of electricity,[10] meaning there is a profit incentive to allocate less pipeline capacity to serve the wholesale natural gas market. Its supply is also positively related to its profits in the wholesale capacity market, discounted by the pass-through rate. I notice that when there is sufficient pipeline capacity, the LDC will supply more to the wholesale market than when constraints bind, holding all else equal.

4.3 Incentives to Supply the Wholesale Natural Gas Market

The primary purpose of this study is to understand firms' motives to distribute pipeline capacity among the various natural gas sectors and whether these allocation decisions are intended to manipulate prices. In particular, under what circumstances, if any, would the decision to minimally supply pipeline capacity to the wholesale market be motivated by increased profits in the electric sector? If there are multiple reasons to minimally supply the wholesale market from an LDC's point of view, what circumstances are likely to favor one motivation over another?

I solve the following to gain some more insight into the problem:

$$Max_{S_W,S_R} E[s_E(p_E - c_E) + \delta S_W(p_W - c_W) + \eta d_R - \alpha(d_R - S_R)p_C] + \lambda(S_{Max} - S_R - S_W) + \mu(S_W - \overline{S}) \tag{13}$$

I find that the shadow value of interruptible service ($S_W \geq \overline{S}$), μ, can be expressed as:

$$\mu = -E[\alpha \frac{\partial S_R}{\partial S_W} p_C + s_E(\frac{\partial p_E}{\partial S_W} - \frac{\partial c_E}{\partial S_W}) + \frac{\partial s_E}{\partial p_E}\frac{\partial p_E}{\partial S_W}(p_E - c_E) + \delta(S_W \frac{\partial p_W}{\partial S_W} + p_W - c_W)] + \lambda(1 + \frac{\partial S_R}{\partial S_W}) \tag{14}$$

In order for the interruptible service constraint to be binding, it must be that $\mu > 0$. Put another way, an LDC utility would choose to only serve its contractual obligations to the wholesale market when:

10. Assuming $s_E(\frac{\partial p_E}{\partial S_W} - \frac{\partial c_E}{\partial S_W}) + \frac{\partial s_E}{\partial p_E}\frac{\partial p_E}{\partial S_W}(p_E - c_E) < 0$.

$$E[s_E \frac{\partial p_E}{\partial S_W} + \frac{\partial s_E}{\partial p_E}\frac{\partial p_E}{\partial S_W} p_E + \delta(S_W \frac{\partial p_W}{\partial S_W} + p_W)] - \lambda(1 + \frac{\partial S_R}{\partial S_W}) <$$

$$E[s_E \frac{\partial c_E}{\partial S_W} + \frac{\partial s_E}{\partial p_E}\frac{\partial p_E}{\partial S_W} c_E + \delta c_W - \alpha \frac{\partial S_R}{\partial S_W} p_C] \quad (15)$$

In this case, the LDC would prefer to sell even less pipeline space to its wholesale customers but it is contractually obligated not to do so. Essentially, inequality (15) states that an LDC will choose not to supply the wholesale market, above its contractual obligations, when the expected marginal revenue from supplying natural gas to the wholesale market is less than the expected marginal costs of doing so. Inequality (15) considers the effect of allocating less pipeline capacity to the wholesale market on profits earned in the electric sector, suggesting a firm may be motivated to allocate less capacity to the wholesale market for manipulative reasons. However, inequality (15) also considers how this allocation affects wholesale market profits and retail penalties, both of which are not manipulative considerations. Importantly, inequality (15) demonstrates that there are multiple considerations a firm takes into account when allocating pipeline capacity and highlights the difficulty this presents in determining whether a firm acted with a manipulative intent.

I consider how these outcomes change when the pipeline constraint binds and does not bind. When there is sufficient pipeline capacity, it will not always be profitable to restrict pipeline capacity to the wholesale market; it could be profitable to do so, however, if a firm has enough capacity such that absent its supply, demand from the wholesale market for pipeline capacity will exceed the remaining pipeline supply. In other words, it could be profitable to reduce supply of pipeline capacity to the wholesale natural gas market if the firm can artificially make the constraint bind by doing so.

I assume that when the pipeline capacity constraint is not binding, $\frac{\partial S_R}{\partial S_W} = 0$ and $\lambda = 0$. I make the assumption that $\frac{\partial S_R}{\partial S_W} = 0$ when the constraint is not binding because this implies that when pipeline capacity is not scarce, a firm that allocates more pipeline space to the wholesale market will not need to reduce the amount of pipeline space it allocates to the retail market. Therefore, when the pipeline constraint is not binding, the following condition must hold for the LDC to minimally supply the wholesale market:

$$E[s_E \frac{\partial p_E}{\partial S_W} + \frac{\partial s_E}{\partial p_E}\frac{\partial p_E}{\partial S_W} p_E + \delta(S_W \frac{\partial p_W}{\partial S_W} + p_W)] < E[s_E \frac{\partial c_E}{\partial S_W} + \frac{\partial s_E}{\partial p_E}\frac{\partial p_E}{\partial S_W} c_E + \delta c_W] \quad (16)$$

When I assume the pipeline capacity constraint is binding, on the other hand, I assume that $\lambda > 0$ and $\frac{\partial S_R}{\partial S_W} = -1$. This in turn implies the LDC will choose to minimally supply the wholesale market when:

$$E[s_E \frac{\partial p_E}{\partial S_W} + \frac{\partial s_E}{\partial p_E}\frac{\partial p_E}{\partial S_W} p_E + \delta(S_W \frac{\partial p_W}{\partial S_W} + p_W)] < E[s_E \frac{\partial c_E}{\partial S_W} + \frac{\partial s_E}{\partial p_E}\frac{\partial p_E}{\partial S_W} c_E + \delta c_W + \alpha p_C] \quad (17)$$

Therefore, from inequalities (16) and (17), we see that when pipeline constraints bind, a vertically integrated LDC is more motivated to allocate less capacity to the wholesale market than when the pipeline has excess capacity, holding all else equal. The increased motivation to withhold capacity when pipeline constraints bind comes from the expected penalty of failing to serve retail customers, which becomes more probable when pipeline capacity is scarce. In the case where the pipeline capacity constraint is not binding, the motivation to restrict supply of pipeline capacity to the wholesale market stems from the goal of increasing marginal profits. The only time a firm could increase its marginal profits in the electricity sector using this strategy would be if it had enough pipeline capacity such that a reduction in its supply to the market would result in demand exceeding the remaining pipeline capacity, creating an artificial constraint. Consequently, it is easier, although still difficult, to detect manipulative behavior when pipeline constraints are not binding as there are fewer confounding factors behind the allocation decision. This finding can serve as a screen for detecting manipulative behavior: if total nominated demand for pipeline capacity does not exceed total pipeline capacity and a firm chooses to restrict its unused capacity such that the pipeline can no longer meet total demand, it is possible that the firm is attempting to manipulate the market.

In such a situation, it would be necessary to determine that the gains from this allocation were mainly experienced in the electric market, and not the wholesale natural gas market, before raising any questions as to whether the firm had acted to manipulate the market.

Binding pipeline capacity constraints, on the other hand, push an LDC further to a corner solution, encouraging the LDC to minimize its sales to the wholesale market in order to avoid expected penalties as well as to increase marginal profits. When pipeline constraints bind it becomes more difficult to determine the reason an LDC has minimally supplied the wholesale market.

The primary vulnerability in making manipulation accusations against LDCs during times of scarce capacity is that it is difficult to distinguish between a utility's desire to increase its profits in the electric sector and/or the wholesale natural gas sector, and its desire to minimize the probability of facing penalties from failing to reserve sufficient pipeline capacity for retail demand. While the former is a potential basis for market manipulation, the latter two can be explained by a willingness to maximize profits with the traditional use of market power and a desire to avoid penalties. There are thus three sources of incentives for an LDC to minimize its allocation of capacity to the wholesale market during times of scarce capacity: increased profits in the electric generating sector (assuming the LDC owns inframarginal supply that is not regulated), increased profits in the wholesale natural gas market (assuming restricting natural gas supply increases the marginal profit), and penalties incurred when reserved retail pipeline space is less than retail demand.

4.4 Policy Implications

The analysis above indicates that it is not sufficient to claim that firms that have allocated less pipeline capacity to the wholesale natural gas market are attempting to manipulate prices. This holds when the pipeline is constrained and when the pipeline has sufficient capacity. However, assuming a firm has enough contracted pipeline supply to be able to change prices by reducing its supply to the wholesale natural gas market, it is easier to detect manipulative behavior when pipeline constraints are not binding. Using this finding, regulators can develop a screen for detecting manipulative behavior by vertically integrated firms in the natural gas and electricity markets. This screen would be triggered when the total nominations for pipeline capacity do not exceed the pipeline's total capacity, i.e., when the pipeline capacity constraint is not binding, and a firm does not sell its unused capacity to the wholesale natural gas market, such that the resulting available pipeline supply is less than demand.[11] In this case, it is possible that the firm is reducing its supply of pipe-

11. The model assumes that S_{Max} is not a choice variable. Consequently, the results of this analysis depend on shippers not being able to change their firm capacity easily or frequently. In other words, from the shipper's point of view, their firm capacity needs to be seen as being fixed.

line capacity to manipulate wholesale natural gas and electricity prices. Once this screen has been triggered, regulators would need to examine the firm's obligations to determine whether the firm sought to manipulate the natural gas and electricity markets, or whether it was motivated by some other reason. Of course, the conditions set forth in the screen are neither sufficient nor necessary to detect manipulation. The proposed screen, however, presents a starting point for regulators to detect possible market manipulations.

Further, the findings of this paper suggest that the current pipeline allocation mechanism creates distortions that need to be considered by policymakers. As the use of natural gas in electricity generation becomes more prominent, policymakers need to determine the optimal allocation of pipeline capacity between the retail and wholesale markets. Should policymakers decide that more capacity needs to be allocated to the wholesale market, the results of this paper can be used to determine mechanisms that will influence the optimal allocation of capacity between the two markets. To incentivize greater pipeline supply to the wholesale natural gas market relative to the retail natural gas market, regulators could allow LDCs to keep a larger portion of the profits generated in the wholesale market, making it a more lucrative and desirable market, an argument made in Marks et al. (2017). This, of course, is assuming marginal profits would augment with increased supplies, which does not always hold. Additionally, a decrease in the penalties for causing pipeline imbalances to serve unexpected retail demand would also increase a firm's incentive to supply pipeline capacity to the wholesale natural gas market.

4.5 Conclusion

In this paper, I provide a theoretical foundation that finds that while there may be an incentive for vertically integrated firms to withhold natural gas pipeline capacity in order to increase their profits in the electric sector, there are other reasons these firms would choose to reduce their supply of natural gas to the wholesale market. These factors become more relevant when there is scarce capacity on the pipeline. When capacity is scarce, LDCs face the risk of severe penalties if they fail to adequately reserve space to meet retail demand. Since demand is uncertain and LDCs must nominate their pipeline capacity prior to observing demand, they are wary of selling their no-notice service to third party shippers as they face potentially large penalties from doing so if demand for retail gas exceeds their ability to supply. This desire to avoid large penalties downwardly biases an LDC's supply of natural gas pipeline capacity from the wholesale market in favor of supply for the retail market.

This analysis presents three interesting conclusions for policy makers. First, the current pipeline allocation mechanism skews supply towards the retail market over the wholesale capacity market, holding all else equal. As natural gas is becoming more prominent in electric generation, and pipeline capacity is increasingly constrained, there is a need for regulators to re-evaluate pipeline allocation mechanisms to optimally allocate supply between the wholesale and retail markets. Since a considerable number of end-users in both the electric and retail markets are households, regulators must determine the optimal allocation of natural gas in both sectors to serve their constituents. Second, I have shown that the problem of allocating natural gas pipeline capacity between the wholesale and retail sectors is exacerbated by limited pipeline capacity and that manipulative behavior is easier to detect when there is sufficient pipeline capacity. Increasing pipeline capacity would thus have two obvious benefits. It would favor increased supply to the wholesale market, holding all else equal, and it would allow regulators to more easily detect market participants attempting to manipulate prices for their own gain. Third, building on the previous observations, a firm that supplies less natural gas pipeline capacity to the wholesale natural gas market could be doing so for a stand-alone legitimate business purpose, such as maximizing profits in the wholesale capacity markets or avoiding retail penalties.

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