Strategic Investments under Open Access: Theory and Evidence[*]

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Abstract

We examine the incentives of access-regulated firms to invest in infrastructure facilities they must share with competitors. We show that investment incentives can be decomposed into a non-strategic and a strategic part. The non-strategic part implies that investment depends positively on market size. The strategic incentives imply that investment also depends on market composition, namely, the market shares of the facility owner and its competitors. Using a dataset of regulated electric utilities in the United States, we find evidence that transmission investments are indeed made strategically. Ceteris paribus, utilities are less likely to invest, and investment levels are lower, when competitors occupy a larger share of the market.

Keywords: Infrastructure investment; network industries; open access; access regulation; electricity wholesale market.

JEL codes: D21, D22, D43, K23, L43, L94.

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1 Introduction

We consider a natural monopoly whose market power derives from network infrastructure that is essential for production of a final good and costly to replicate. The firm can thus extend its upstream monopoly power into potentially competitive market segments. Traditionally, states regulated the monopoly's operations in these segments. In the 1980s and 1990s, however, policy makers in the United States and elsewhere began adopting a liberalization program aimed at opening networks in vertically integrated monopolies. Open network access forces network operators to lease their facilities to competitors at regulated rates, leaving service offerings and prices to be determined by competition in the end-user market.[1] The implementation of open access has generally been successful in facilitating competition in previously closed market segments, with positive effects on allocative efficiency.

One may be concerned, however, that requiring a firm to share its network with competitors takes away its economic incentive to invest in it, thus diminishing the long-run, dynamic efficiency of the market. In Klumpp and Su (2010), we examined a theoretical model of open access regulation to show that the opposite may be the case: When access pricing is *revenue neutral*—which, in our context, meant that the terms of access are fair, reasonable, and non-discriminatory—then investments under open access depend positively on allocative efficiency in the deregulated segment. This prediction relies on a number of assumptions. In particular, in Klumpp and Su (2010) we assumed a linear demand function, symmetric costs across firms, and riskless investments. Clearly, each of these conditions is likely to be violated in reality. The results in Klumpp and Su (2010) should therefore be viewed as describing a reference case that shows what is possible under a well-designed open access regime.

In this paper we extend the framework of Klumpp and Su (2010) by allowing for a larger class of demand functions and cost structures. The price of this generality is that unambiguous predictions concerning the regulated firm's investments can no longer be obtained. However, we show that one important feature of the more restrictive model nevertheless carries over to the general case: The regulated firm's incentive to invest can be decomposed into a non-strategic part and a strategic part. The non-strategic part depends only on the industry's aggregate output, but not on the composition of the market, and implies an increase in upstream investments the more successful open access is at increasing downstream output. The strategic part depends on the impact of the integrated firm's investment on its competitors' downstream actions, and may go in the same or

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[1] Access requirements are found, for example, in the 1992 U.S. Energy Policy Act, the 1996 U.S. Telecommunications Act, and similar laws in other countries. These requirements are enforced by regulatory agencies such as the Federal Energy Regulatory Commission and the Federal Communications Commission.

the opposite direction as the non-strategic effect. The balance of both effects is hence ambiguous, so that gains in static efficiency from open access can cause gains as well as losses in dynamic efficiency. The latter will be the case whenever the strategic effects are sufficiently strong and of the opposite direction of the non-strategic ones.[2] But even if the balance of investment incentives remains positive, one may still be concerned with their relative strength and the potential impact of strategic effects on investments and competition. The overall impact of access regulation on network investments is, therefore, ultimately an empirical question. We demonstrate how our decomposition of investment incentives into a nonstrategic and a strategic part can be utilized to guide such empirical investigations.

Our application concerns investments in power transmission infrastructure in the U.S. electricity wholesale market. In this market, the 1992 U.S. Energy Policy Act enables independent power producers (IPPs) to compete alongside traditional integrated utilities, by requiring the latter to open their electric transmission networks to the former.[3] We use a dataset of 78 regulated electric utilities containing information of transmission investments and operations in the generation segment by these utilities over an 11-year span (2000–2010), gathered from mandatory filings made by integrated utilities to the Federal Energy Regulatory Commission (FERC). In agreement with the non-strategic investment incentive that we isolate in our theoretical framework, we indeed find that transmission investments depend positively on total market size. We also find that, after controlling for market size, transmission investments depend significantly and negatively on combined power generation by competitors. This finding is consistent with the strategic hypothesis, namely that utilities take into account the impact of their investments on competitors' production decisions. The strategic considerations run in the opposite direction of their non-strategic incentives. Furthermore, the estimated coefficients on competitors' output and total output are of comparable magnitude, indicating that strategic effects are quantitatively important.

The methodological approach we develop, and the empirical results we obtain in our application, are a step toward a quantitative evaluation of investment incentives in network industries under open access regulation. An economy's network infrastructure is critical for both its current welfare and its long-term growth. Conventional wisdom holds that forcing a firm to share the fruits of its infrastructure investments with com-

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[2] Under the assumptions of Klumpp and Su (2010), the strategic effect never overrides the non-strategic effect, so that an increase in downstream output always increases upstream investments.

[3] Transmission is the high-voltage transport of electric energy ("power") from generation sites to load centers. Generation and transmission together constitute the wholesale market of the industry. In accordance with our model, transmission is the upstream (network) segment, and generation the downstream segment, of the wholesale market. (Of course, the technological flows of production imply that power is generated before it is transmitted.) The low-voltage, "last mile" distribution to consumers constitutes the electric retail market.

petitors will reduce the firm's incentives to invest in the long run. However, it is not the mandatory sharing of an asset *per se* that reduces investments: The direct, non-strategic investment incentives (in theory and in the data) actually imply the opposite. Instead, the competitors' response to an investment alters its profitability at the margin, either positively or negatively. Which of these is the case, and how strong this strategic impact is, depends on the market in question and can be discovered from industry data. In the U.S. electricity wholesale market, the estimated strategic and non-strategic effects are of comparable strength, and run in the opposite direction. Thus, gains in static efficiency in the power generation segment (e.g., from sustained entry of new IPPs) have the potential to reduce total investments in power transmission infrastructure.

The remainder of the paper is organized as follows. In Section 2, we review the related literature. In Section 3, we present a theoretical model of an access-regulated industry and discuss both the non-strategic and the strategic effects in detail. We then turn to our empirical application. In Section 4, we provide background information of the U.S. electricity wholesale market under open access, and describe our dataset of regulated utilities in this market. Our empirical analysis is conducted in Section 5. Section 7 concludes.

2 Related Literature

There is a theoretical literature on pricing of access to essential physical infrastructure, and in particular network infrastructure—good analytical treatments of various access pricing rules can be found in Berg and Tschirhart (1988), Armstrong et al. (1996), Laffont and Tirole (2001) and Vogelsang (2003), among others. In addition, an extensive literature is concerned, specifically, with impacts of open access restructuring on the U.S. wholesale electricity generation sector. One strand of this literature focuses on the importance of vertical arrangements between wholesale sellers and wholesale buyers to prevent the exercise of market power (Borenstein 2002; Mansur 2007; Bushnell *et al.* 2008; Bushnell 2007), and on the ability of generation firms to exercise market power after restructuring (Borenstein and Bushnell 1999; Borenstein *et al.* 2002; Wolak 2003). A second strand focuses on the impact of restructuring on generation efficiency and environmental impacts (Kleit and Tecrell 2001; Fabrizio *et al.* 2007; Zhang 2007; Barmack *et al.* 2007; Fowlie 2010).

The aforementioned literature largely focuses on the effects of open access on efficiency in the downstream market—both allocative efficiency through its impact on market power, and productive efficiency through its impact on investments in generation technology. Our paper, on the other hand, is concerned with investments in the transmission network, that is, in the upstream (bottleneck) segment. Potentially adverse effects on upstream dynamic efficiency are sometimes used in arguments against open access policies (see, for instance, Sidak and Spulber, 1996). Recent analytical results, however, support the opposite conclusion in some cases. Foros (2004) shows that an integrated firm may have strong investment incentives when access rates reflect the network's marginal cost but do not depend on the investment in it. Klumpp and Su (2010) examine a linear access tariff that depends on the investment and allows the network owner to recover exactly its investment cost in equilibrium. Klumpp and Su (2100) show that this policy can create a causal link from increased downstream efficiency to increased upstream investments. (Linear tariffs are subsumed in the set of tariffs we consider in the present paper.)

Both Foros (2004) and Klumpp and Su (2010) assume that there is a clearly defined integrated firm (i.e., the incumbent) which competes against a set of downstream competitors. Other papers examine models that impose no such asymmetry on the firms. Gans and Williams (1998), Gans (2001), and Haucap and Dewenter (2006) consider innovation races between several identical firms and show that two-part access tariffs can induce investment at the socially optimal time. Valletti and Cambini (2005) consider investment incentives in the context of two-way access pricing for interconnected communications networks, and show that firms reduce their investments if access fees are set at marginal cost or above. Jeon and Hurkens (2008) show that static and dynamic efficiency can be achieved in two-way access if access charges are set below marginal cost. Bourreau *et al.* (2013) examine two-way access in a framework with demand uncertainty, and show that mandatory access decreases infrastructure investment, relative to voluntary access.

Finally, the empirical literature on the effects of access regulation on infrastructure investment is relatively scant. In fixed-line telecommunications, open access takes the form of mandatory local loop unbundling. Crandall *et al.* (2004) find that mandatory unbundling in the U.S. reduces investments by entrants relative to investments by incumbents, thus suggesting that access regulation fails to promote facilities-based competition. However, this study does not examine how access affects either the incumbents' investments or the competitors' investments in absolute terms. For European countries, Friederiszick *et al.* (2008) find that mandatory unbundling discourages infrastructure investment by entrants, but has no significant effect on incumbents' investments.

We are not aware of any studies that try to empirically determine the impact of access regulation on electric transmission investment, either by incumbents or by third-party merchants. In a survey of the literature on investment in regulated infrastructure industries, Guthrie (2006) writes:

> "Almost ten years have passed since the Telecommunications Act transformed telecommunications regulation in the United States and economists still do not have a thorough understanding (theoretically or empirically) of

> how local loop unbundling affects investment. *Understanding of the investment response to electricity transmission pricing is even less developed.* More study of access regulation and its impact on investment behavior [...] is needed." (Emphasis added.)

The present paper is a step toward filling this gap.

3 Theoretical Model

The following model generalizes the one in Klumpp and Su (2010). We consider a vertical industry consisting of an upstream infrastructure segment, called the network, and a downstream segment in which a final good is produced and sold. Production of one unit of the final good requires one unit of network services. Once deployed, the network is an excludable but non-rivalrous good (i.e., a club good) that can provide an unlimited amount of network services at zero marginal costs.[4]

The network is characterized by its quality, $\theta \geq 0$. Building a network of quality θ requires an investment of $F(\theta)$, with $F' > 0$ and $F'' > 0$. Given quality θ, the downstream market for the final good is characterized by the inverse demand function $P = P(\theta, Q)$. We assume that $P_Q < 0$, $P_\theta > 0$, $P_{\theta\theta} \leq 0$, and $P_{\theta Q} \geq -P_\theta/Q$. These assumptions are satisfied for many commonly used demand functions. For example, let $G(Q)$ be a strictly increasing function. Then our model includes the demand function $P(\theta, Q) = a\theta - G(Q)$ (demand shifting) as well as $P(\theta, Q) = a - G(Q)/\theta$ (demand stretching).

There are $n+1$ firms in the market. Firm zero, which we call the incumbent, is a vertically integrated firm that owns and controls the network and also produces the downstream good. Firms $1, \ldots, n$ are entrants that do not operate their own upstream networks, but stand ready to compete as Cournot players in the downstream market. We denote firm i's downstream quantity by Q_i ($i = 0, \ldots, n$). The combined quantity of all firms us $Q = Q_0 + \ldots + Q_n$. Firm i's cost of producing Q_i units of the final good is $C_i(Q_i)$, with $C_i' \geq 0$.

3.1 Open access regulation and downstream competition

Under open access regulation, the incumbent is required to lease its essential facilities to downstream competitors at a tariff that is *Fair, Reasonable, and Non-Discriminatory (FRAND)*.[5] Formally, the FRAND standard is modeled as follows.

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[4] This assumption holds within bounds only, as networks may become congested. The problem of congestion is relevant for our empirical application and will be discussed in Section 4.1.

[5] Such language is contained, for example, in the 1992 Energy Policy Act (Sect. 722 (1)) and the 1996 Telecom Act (Sect. 251 (c), 252 (d)).

Let $T : \mathbb{R}_+ \to \mathbb{R}$ map firm i's quantity Q_i into an access payment $T(Q_i)$ that i must remit to the incumbent. Let $Q_i^*(\theta, T)$ denote firm i's equilibrium output in the downstream market, given demand curve $P(\theta, \cdot)$ and access tariff T. Let $Q^*(\theta, T)$ be the aggregate equilibrium output and let $\gamma_i^*(\theta, T) \equiv Q_i^*(\theta, T)/Q^*(\theta, T)$ be firm i's market share in equilibrium. Then T satisfies the FRAND principle if, in equilibrium,

$$T(Q_i^*(\theta, T)) \;=\; \gamma_i^*(\theta, T)F(\theta) \tag{1}$$

for all i (including the incumbent). Thus, the *average* cost of network services is the same for all firms, namely $F(\theta)/Q^*$. Furthermore, the sum of all access payments—including the "accounting payment" $T(Q_0^*)$ the incumbent makes to itself—is sufficient to recover the network investment, but not more than it. A zero profit condition is hence imposed on the incumbent's network leasing business. Tariffs that satisfy (1) could be linear (i.e., $T(Q_i) = tQ_i$) or non-linear (e.g., a lump-sum transfer or two-part tariff).

Entrant i's profit function is $\pi_i(Q_i) = Q_i P(\theta, Q) - C(Q_i) - T(Q_i)$, and the first-order condition for a maximum is

$$\frac{\partial}{\partial Q_i}\pi_i \;=\; Q_i P_Q(\theta, Q) + P(\theta, Q) - C_i'(Q_i) - T'(Q_i) \;=\; 0. \tag{2}$$

Note that unless T is a lump-sum transfer ($T' = 0$), an entrant's cost of accessing the network is part of its variable operating costs.

The incumbent's profit function is $\pi_0(\theta, Q_0) = Q_0 P(\theta, Q) - C_0(Q_0) + \sum_{i=1}^n T(Q_i) - F(\theta)$, and the first-order condition for a maximum (with respect to Q_0) is

$$\frac{\partial}{\partial Q_0}\pi_0 \;=\; Q_0 P_Q(\theta, Q) + P(\theta, Q) - C_0'(Q_0) \;=\; 0. \tag{3}$$

Note that the payment $T(Q_0)$ is simply an internal transfer within the integrated firm. Unlike the entrants, the incumbent does not treat the access tariff as a variable cost.

Consider now a Cournot equilibrium $Q_0^*, \ldots, Q_n^*$ in the downstream market and suppose the FRAND principle (1) holds. This implies that $\sum_{i=1}^n T(Q_i) - F(\theta) = (\sum_{i=1}^n \gamma_i^* - 1)F(\theta) = -\gamma_0^* F(\theta)$, so that the incumbent's equilibrium profit can then be expressed in a manner symmetric to an entrant's profit:

$$\pi_0^* \;=\; Q_0^* P(\theta, Q^*) - C_0(Q_0^*) - \underbrace{\gamma_0^* F(\theta)}_{T(Q_0^*)}. \tag{4}$$

However, the same is not true for the incumbent's profit *function*: Unless T is lump-sum, the presence of T in the entrants' variable costs confers a competitive advantage to the incumbent in the downstream market. Thus, the incumbent can use its network investment as a strategic tool to raise the entrants' marginal costs relative to its own (even though it is strictly prohibited from raising entrants' total costs).[6] We will discuss the strategic value of upstream investments in the next section.

3.2 Upstream investment

Let us now turn to the incumbent's choice if network quality θ. Anticipating regulation in the downstream market, the incumbent takes the FRAND principle as a constraint. We use (4) to write the first-order condition for a maximum of π_0 with respect to upstream quality θ as

$$\begin{aligned} \frac{d}{d\theta}\pi_0^* \;=\; & Q_0^*\left[P_\theta(\theta,Q^*)+P_Q(\theta,Q^*)\frac{dQ^*}{d\theta}\right] + \frac{dQ_0^*}{d\theta}P(\theta,Q^*) \\ & - \frac{dQ_0^*}{d\theta}C_0'(Q_0^*) - \gamma_0^*F'(\theta) - \frac{d\gamma_0^*}{d\theta}F(\theta) \;=\; 0. \end{aligned} \tag{5}$$

Substituting the incumbent's downstream first-order condition (3) into (5) and rearranging, the upstream first-order condition can be expressed as follows:

$$\underbrace{Q_0^*P_\theta(\theta,Q^*)}_{\substack{\text{Non-strategic}\\ \text{revenue effect}}} \;+\; \underbrace{Q_0^*P_Q(\theta,Q^*)\frac{dQ^*_{-0}}{d\theta}}_{\substack{\text{Strategic}\\ \text{revenue effect}}} \;=\; \underbrace{\gamma_0^*F'(\theta)}_{\substack{\text{Non-strategic}\\ \text{cost effect}}} \;+\; \underbrace{\frac{d\gamma_0^*}{d\theta}F(\theta).}_{\substack{\text{Strategic}\\ \text{cost effect}}} \tag{6}$$

Condition (6) decomposes the integrated firm's investment incentive into non-strategic and strategic effects. Non-strategic effects are components of (6) that do not depend on the adjustment of downstream quantities in response to changes in upstream quality. If such adjustments were neglected, the incumbent's optimal investment would be characterized by equality of the non-strategic cost and revenue effects. Since $Q_0^* = \gamma_0^*Q^*$, we can express this equality as

$$\gamma_0^*Q^*P_\theta(\theta,Q^*) = \gamma_0^*F'(\theta) \quad \Leftrightarrow \quad Q^*P_\theta(\theta,Q^*) = F'(\theta). \tag{7}$$

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[6] Anticompetitive practices that increase opponents' costs have been a longstanding concern in the antitrust literature; see Salop and Scheffman (1983, 1987), Krattenmaker and Salop (1986), Brennan (1988), Economides (1998), Granitz and Klein (1996). The strategic incentive in our paper gives rise to a more subtle and constrained form of the practice than what is examined in this literature. The practice is furthermore legal in our context, as the firm is prevented from earning a supra-competitive profit from leasing its infrastructure to rivals.

This is the same as the optimality condition on θ if the incumbent were an unregulated monopoly in both the upstream and the downstream market (i.e., the marginal benefit of quality equals the marginal cost of quality). Implicitly differentiating both sides of (7) with respect to Q^*, we have

$$\frac{d\theta}{dQ^*} = \frac{P_\theta(\theta, Q^*) + Q^* P_{\theta Q}(\theta, Q^*)}{F''(\theta) - Q^* P_{\theta\theta}(\theta, Q^*)} \geq 0. \tag{8}$$

That is, the larger is the downstream market size Q^*, the stronger is the incumbent's incentive to invest in quality θ. This will be true regardless of the cause of the increase in Q^*, which could be an exogenous demand shock, a cost reduction by the incumbent, a cost reduction by existing competitors, or entry of new competitors.

In response to changes in θ and $F(\theta)$, the access tariff T must adjust to remain FRAND-compliant. Since T is part of each entrant's variable costs, the downstream quantities will in turn adjust, and so will the firms' market shares. Thus, the incumbent's choice of upstream quality affects its competitive advantage over the entrants in the downstream market. This link between upstream investments and downstream market shares gives rise to strategic effects in the investment decision. Consider first the strategic revenue term in (6). Since demand is downward sloping, if $dQ^*_{-0}/d\theta$ is positive the strategic revenue effect weakens the incumbent's incentive to invest, and if $dQ^*_{-0}/d\theta$ is negative, the incentive to invest is strengthened. Similarly, if $d\gamma_0^*/d\theta$ is positive the strategic cost term in (6) weakens investment incentives, and if $d\gamma_0^*/d\theta$ is negative it strengthens them.

Condition (6) suggests an empirical test for the presence of strategic investment effects. Suppose we observe output and investment data in a network industry under access regulation. If, after controlling for market size (Q^*), investment depends on market composition (Q_0^* v. Q^*_{-0}), the incumbent must have taken the strategic revenue and strategic cost terms into consideration. The strength and direction of this dependence can then be compared to the non-strategic effect, which is given by the relationship between market size and investment and predicted to be positive (condition (7)). In the following sections, we demonstrate this approach in the context of the U.S. electricity wholesale market.

4 The U.S. Electricity Wholesale Market

In this section we provide some background of the electricity industry in the United States and argue that our theoretical model is applicable to this market. We then describe our dataset of investments and firm characteristics.

4.1 Industry background

The U.S. electricity industry is divided into three segments: generation, transmission, and distribution. Generation and transmission together constitute the wholesale market. In this market, electricity is produced in power plants and transported from generation sites to load centers through the transmission grid. The remaining segment, distribution, constitutes the retail market. In this market, electricity is received from the transmission grid and distributed through the distribution network to final consumers, such as residential households, commercial properties, and industrial users.

Traditionally, electric utilities were vertically integrated and fully regulated monopolies, responsible for generation, transmission, and distribution. Retail operations are typically regulated at the state and local level, and wholesale operations at the federal level. Starting in the late 1990s, the Federal Energy Regulatory Commission (FERC) began issuing a series of orders aimed at promoting wholesale competition through "open access non-discriminatory transmission services."[7] With open access to the transmission grid, independent power producers (IPPs) are able to participate in the wholesale market by building their own generation facilities without having to deploy costly transmission infrastructure. Today, more than $1,700$ IPPs operate alongside traditional utilities throughout the United States.[8]

In accordance with our model, we regard transmission as the upstream (bottleneck) segment of the wholesale market, and generation as the downstream segment.[9] The geographic boundary of the market is the "balancing authority area" (previously known as the control area), which is the area served by the transmission network of a given utility. More specifically, since wholesale competition allows a utility to reach markets beyond its own balancing authority area, a utility is regarded as firm 0 only in its own market, but treated as an entrant in other markets. Furthermore, different options exist for utilities to comply with open access regulation. If a utility *functionally* separates its transmission and generation operations—for example, by letting an Independent System Operator (ISO) or a Regional Transmission Organization (RTO) administer its transmission grid—this utility is still vertically integrated in our model's sense, because it still owns its transmission assets and can use transmission investments as a strategic tool to influence competition in the generation segment. On the other hand, if a utility *structurally* divests its transmission assets to another company, it is no longer vertically integrated in our model's sense.

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[7] See Federal Energy Regulatory Commission, Orders No. 888, No. 889, and No. 890 (available online at www.ferc.gov/legal/maj-ord-reg.asp).

[8] Source: Department of Energy, Energy Information Administration.

[9] That is, upstream and downstream segments are distinguished by their economic characteristics. The physical flow of power begins at the site of generation and then continuous through the transmission network to load centers.

Unlike the upstream network in our model, the electricity transmission grid can become congested and the actual or scheduled power flow over the grid is restricted below the level requested by transmission users. We distinguish physical congestion and economic congestion. Physical congestion is the failure to balance electricity supply and demand in real time, resulting in load loss (blackouts). Physical congestion is relatively rare: Within the North American bulk power system, there have been fewer than 15 unplanned transmission-related events in each year since 2002 that resulted in load losses of more than 300 MW for more than 15 minutes (North American Electric Reliability Corporation 2013). Economic congestion, on the other hand, means that supply and demand are balanced but low-cost power is prevented from reaching load centers due to transmission constraints. When this happens, high-cost power is substituted within the constrained area to meet demand, translating into economic rents associated with transmission rights. The effective access rate to the transmission grid thus depends on a variety of factors excluded from our model.[10] Several geographic areas in the U.S. are prone to economic congestion (Department of Energy 2009).

While FERC allows transmission pricing to be flexible to accommodate economic congestion, it requires integrated utilities to use the rates, terms, and conditions of its own use of the transmission system as a benchmark for third-party access to the grid. Furthermore, FERC requires that flexible transmission pricing meet the "traditional revenue requirement" of fair, reasonable, and non-discriminatory rates.[11] Thus, despite the caveat of potential congestion, our theoretical model captures the essence of actual policies governing transmission access and pricing in the U.S.

4.2 Data and sample selection

We use annual FERC Form 1 data for our empirical analysis. Form 1 is a comprehensive financial and operating report used for electricity rate regulation and financial audits that all major electric utilities are required to submit. Using Form 1 reports, we obtain annual utility-level data on both upstream transmission networks and downstream power generation and disposition over eleven years, from 2000 through 2010.

Transmission network data. Form 1 reports information on both a utility's annual investments in its transmission networks (a flow variable) and a utility's total transmission assets at the end of each year (a stock variable). Both investments and assets are measured

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[10] Some papers in the literature concerned with the physical flows of electricity through transmission networks argue that location-based nodal pricing for transmission services can reflect the costs of congestion and thus encourage investment by third parties (merchants); see Vogelsang (2001), Brunekreeft (2004), Jaskow and Tirole (2005).

[11] See Federal Energy Regulatory Commission, *1994 Transmission Pricing Policy Statement* (Docket No. RM93-19-000).

in two ways: Physical, that is, the length of new or existing transmission lines; and monetary, that is, the cost of new or existing transmission lines. Each measure has advantages and shortcomings. On the one hand, when a utility makes certain upgrades to an existing transmission line (for example, increasing its capacity or replacing an overhead line with an underground line), these investments are better captured by their cost instead of the length of new lines, which will often be close to zero. On the other hand, if a utility constructs entirely new lines, these investments are better captured by their length instead of their costs, since otherwise identical lines would be associated with different costs when installed in different years. In a few instances, positive values for the length measure are reported, but zero or missing values for the cost measure, indicating potential measurement errors.[12]

Power generation and disposition. Form 1 also reports an energy balance sheet for each utility, containing the source of energy on one side and the disposition of energy on the other. In terms of energy source, total energy consists of the following: Energy generated by the utility itself ("own generation"); energy generated by competitors and purchased by the utility ("power purchase"); and energy generated by competitors, flowing through the utility's transmission network, and delivered to purchasers other than the utility itself ("wheeling-in" minus "wheeling-out"). On average, a utility's own generation accounts for about two thirds, and its power purchase for about one third of total energy, while average net wheeling is close to zero. On the disposition side, total energy is either used to serve a utility's own final customers ("load"), or is sold to other entities to serve their final customers ("sales for resale"). On average, load represents about three quarters, and sales for resale represent about one quarter, of total energy.

For the period 2000–2010 there were 359 distinct reporting entities with a total of $3,753$ Form 1 reports. From this universe, our empirical analysis focuses on 78 entities and 858 observations. We selected this sample in three steps.

First, recall that our theoretical model concerns the investment decisions made by vertically integrated electric utilities that operate both generation facilities and transmission infrastructure ("firm 0s"). The majority of FERC Form 1 reports in our initial database do not belong to this category: $2,351$ observations report no power generation, and $1,800$ observations report no transmission assets. In total, there are $2,525$ observations that contain a zero entry for either power generation or transmission assets or both. These entities must be excluded from the sample, as our model does not describe their investment decisions. After dropping these $2,525$ observations, we are left with $1,228$ observations for 165 integrated wholesale firms.

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[12] The correlation coefficient between physical and monetary measures for new investment is 0.46. The correlation coefficient between physical and monetary measures for total transmission assets is 0.84.

Second, while our model assumes that integrated utilities are active in power generation and power transmission, it does not require that these firms also serve the retail market. Wholesale demand could be derived from load-serving responsibilities fulfilled by separate retail firms. However, FERC Form 1 contains no information on the balancing authority area within which each reporting entity operates. Without detailed information about the geographic locations of interconnected transmission lines, we cannot match utilities with their competitors in distinct geographic markets. As a shortcut, we rely on load data to capture the size of the wholesale market.[13] Because only load-serving firms report load data, we focus on utilities that are vertically integrated in wholesale *and* retail operations. Accordingly, we exclude 156 observations that report a zero load, leaving 139 distinct entities and $1,072$ observations showing activity in all three segments (generation, transmission, and load-serving).

Finally, not all of these entities have complete reporting histories for the period 2000–2010. Some utilities ceased operations during the sample period.[14] Others experienced changes in their corporate structure, either being acquired by another utility or spun off from another utility.[15] Most importantly, a number of reporting entities experience changes in their operational structure due to wholesale restructuring. For example, five utilities in Wisconsin fully divested their transmission assets to the American Transmission Company in 2001, and major Illinois utilities fully divested their generation assets in various years. These utilities were vertically integrated at the beginning of the sample period but not at the end. Since transmission investment is a long-term decision, one can reasonably expect that firms face different incentives if they foresee a near-term structural change. Thus, we eliminate those utilities that do not have a complete reporting history, and focus on the ones that operated in a business-as-usual fashion for the entire sample period. The business-as-usual requirement further removes 61 reporting entities with a combined 214 observations.[16] This leaves a final sample of 78 reporting entities and 858 observations (78×11).

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[13] Compared to total energy, load is more exogenous and driven by demand in the electricity retail sector. Consider two utilities a and b within neighboring geographic markets A and B, with utility a (b) being the vertically integrated firm in market A (B). If, for example, a purchases power from b during summer months and sells the same amount to b during winter months, total energy in each market would increase even though the load in each market stays constant.

[14] E.g., Montana Power Company ceased operation as a regulated utility and restructured itself as a telecommunications company during the dot-com bubble of the early 2000s. It subsequently incurred heavy losses and filed for bankruptcy in 2003.

[15] E.g., Savannah Electric and Power Company was acquired by Georgia Power in 2006, and Entergy Gulf States was split into Entergy Gulf States Louisiana and Entergy Texas in 2008.

[16] The average reporting length of these 61 entities as vertically integrated utilities is only 3.5 years, compared to 11 years if they had complete reporting histories.

Table 1 displays summary statistics for our sample, broken down by investment, network size, market size, and market composition variables. The bottom panel in Table 1 compares the transmission and energy statistics in our sample of utilities to those of the entire universe of FERC Form 1 reports. On average, the selected utilities account for roughly two thirds of national aggregate load and two thirds of national transmission assets, but they account for four fifths of aggregate own generation and only one half of aggregate power purchase. In terms of new transmission investments, the selected firms represent 54.8% of new line length and 64.9% of new line cost.

5 Empirical Approach

In this section we describe our empirical approach. We begin by discussing the main variables used in the empirical analysis. We then describe our regression models, as well as discuss identification of the model.

5.1 Main variables

Our theoretical model is a one-period model in which the upstream infrastructure is established in the beginning, utilized, and then fully depreciated at the end of the period. Applied to the electricity wholesale market, this single model period would correspond to the entire life span of transmission assets, which is typically upward of 50 years and hence much longer than our sample period. This static perspective is clearly impractical for our empirical analysis, as a very large fraction of the current stock of transmission assets was deployed prior to the sample period.[17] Moreover, most of these investments occurred prior to the introduction of open access regulation, when utilities faced different investment incentives than they do today. (In particular, lacking competition in the generation segment, transmission investments could not have been based on the strategic incentives explored in our theoretical analysis.) In order to capture investment incentives under open-access regulation and wholesale competition, we use a utility's *annual* transmission investments during the period 2000–2010 as our dependent variable. As described in Section 4.2, both a physical and a monetary measure of annual investments are available (i.e., new line length and new line cost). For robustness purposes, we utilize both measures in our analysis.

Our main explanatory variable is the power generated by a utility's competitors. There are two possible measures for this variable in a given market, one broad and one narrow. The broad measure is the sum of power purchase and power wheeling-in,

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[17] In our sample, annual transmission investment accounts on average for only 0.5% of the existing stock in terms of line length, and for only 2.9% in terms of cost.

and the narrow measure is power purchase alone. We prefer the broad measure for the following reason: Wheeling-in power is physically available in a utility's market and constrains the integrated utility's ability to generate and market high-cost electricity. It thus represents competitive pressure on the integrated firm, even if it ultimately ends up in a market not served by this utility. When the utility's marginal generation cost (and hence purchase price) exceeds that of other purchasers, wheeling power can switch purchasers instantaneously if it is transacted in the spot market, or after some time lag if it is transacted under a long-term agreement. We therefore primarily focus on the broad measure for competitor generation, and use the narrow measure as a robustness check.

Finally, we use a utility's load in a given year as a control variable capturing its market size, as discussed already in Section 4.2. In addition, we control for a utility's existing transmission assets at the beginning of each year. Depending on whether we use a physical or monetary measure for our investment variable, existing network assets will be measured either in physical terms (total line length) or monetary terms (total line cost).

5.2 Regression models of network investment

Let us now turn to our regression models that relate transmission investment and competitor generation.

The main challenge we must address is the fact that annual investments are left-censored. Once a transmission facility is constructed, the investment is irrevocable and sunk. If, at a later time, a utility wants to reduce its stock of transmission capacity, it is unlikely that it will be able to do so. As a consequence, we observe almost no negative investments in our dataset, even though the optimal investment from the utility's point of view might have been negative in many instances.[18] On the other hand, approximately 40% of observations in our sample have zero entries for the investment variables. Ignoring this censoring feature and using a linear model of transmission investments would bias the estimates toward zero (Greene 2011 Ch. 19; Wooldridge 2010 Ch. 17).

We use two techniques to deal with censoring. First, we ignore the magnitude and consider only the sign of the dependent variable. That is, we create a binary outcome variable that takes the value one if investment is positive, and zero otherwise, and estimate the investment probability alone. By ignoring the magnitude of investments, this approach offers a robust but less efficient estimate of the underlying parameters that govern a utility's investment decision. Second, we estimate a panel Tobit model, which utilizes both the probability of investments and variation in the magnitude of

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[18] Out of 858 observations in our dataset, only eleven observations contain a negative value for new line length, and only four observations contain a negative value for new line cost. Interestingly, there are no observations for which both variables are negative, which would correspond to true divestment actions.

observed investments. If the model is not misspecified, this approach offers a more efficient estimate of the underlying parameters; however, this model is more sensitive to misspecification errors.

Let I_{it}^* be a latent variable that represents utility i's optimal investment in year t. I_{it}^* can be positive, zero, or negative, depending on market conditions. We assume that this optimal investment is governed by the regression equation

$$I_{it}^* = u_i + \alpha_t + \beta_1 \,\mathrm{COMPGEN}_{i,t-1} + \beta_2 \,\mathrm{LOAD}_{i,t-1} + \beta_3 \,\mathrm{NETWORK}_{i,t-1} + \varepsilon_{it}. \tag{9}$$

In (9), for utility i and year t, $\mathrm{COMPGEN}_{i,t-1}$ denotes competitor generation in the previous year (i.e., year $t-1$), $\mathrm{LOAD}_{i,t-1}$ captures the total market size in the previous year, and $\mathrm{NETWORK}_{i,t-1}$ is the existing value of total transmission assets at the end of year $t-1$. u_i is a time-invariant utility-specific effect, α_t is a utility-invariant year fixed effect, and ε_{it} is the error term.

In the binary case, the latent variable I_{it}^* is transformed into observed investment I_{it} as follows:

$$I_{it} = \begin{cases} 1 & \text{if } I_{it}^* > 0, \\ 0 & \text{otherwise.} \end{cases} \tag{10}$$

In the Tobit case, the latent variable I_{it}^* is transformed into observed investment I_{it} as follows:

$$I_{it} = \begin{cases} I_{it}^* & \text{if } I_{it}^* > 0, \\ 0 & \text{otherwise.} \end{cases} \tag{11}$$

5.3 Identification

In our theoretical model, both the upstream investment and the downstream market outcome are simultaneously determined in equilibrium. In this sense, the causal relationship between investment decisions and market outcomes runs both ways: An upstream investment affects the access tariff and hence the outcome of downstream competition; and downstream competition affects the share of cost recovery by the integrated utility and hence its upstream investment decision. Our empirical analysis, on the other hand, focuses on only one direction: The effects of downstream competition on upstream investments. This is achieved by using lagged variables on the right-hand side of (9), which are predetermined when the utility makes its current investment decision: Even though upstream investment decisions do affect contemporaneous outcomes in the downstream market, they are unlikely to affect market outcomes in the previous year. Therefore, we interpret our coefficients as representing a causal relationship between downstream market outcomes and upstream investments, in the sense of Granger causality.

Transmission investment can also depend on many other factors not explicitly included in the right-hand side of (9), such as population density of the service area, the availability of natural resources used in generation, or the political environment. Provided that these factors remain stable over time, they are captured by our time-invariant utility-specific effect u_i. If these factors vary over time, but their variation is uncorrelated with our explanatory variables (i.e., $\text{COMPGEN}_{i,t-1}$, $\text{LOAD}_{i,t-1}$, $\text{NETWORK}_{i,t-1}$), they are captured by the error term ε_{it} and do not bias our parameter estimates. However, if these factors do vary over time and their variation is somehow correlated with our explanatory variables, they would pose an omitted variables problem that could bias our estimates. As a sensitivity test, we also estimate the models including a lagged dependent variable on the right-hand side. If, after controlling for existing explanatory variables, a utility's current investment decision still depends significantly on its past investment, this is an indication that omitted variables, as captured by the lagged dependent variable, can bias our estimates. On the other hand, if the lagged dependent variable is insignificant, we can be reasonably assured that omitted variables do not significantly bias our estimates.

6 Estimation Results

We now discuss our estimation strategies for both the binary choice model and the Tobit model, and describe the estimation results.

6.1 Binary choice model

We estimate the binary choice model (10) using panel data linear probability models (LPM). Despite its obvious caveats—predicted probabilities can lie outside of $[0,1]$ and the error term is heteroscedastic—the linear specification has several important advantages. First, the point estimates of the LPM represent marginal effects. Second, while the incidental parameters that capture utility and year fixed effects pose significant challenges for the estimation of nonlinear models, they are easily differenced out in LPMs. Third, LPMs allow for a flexible specification of the error term structure. In particular, one can use the Sargent-Hansen test to determine whether there is a significant difference between fixed and random effects specifications with clustered standard errors.

Estimation results for the LPM are reported in Table 2. In panel A, we use the broad measure for competitor generation (power purchase plus wheeling-in). In each of columns (1)–(4), we report both the fixed effects and the random effects specifications, and use the Sargent-Hansen test to for significant differences between the two. The point estimates on competitor generation are highly significant at the 1%-level and quantitatively robust across all specifications. On average, a 1 TWh increase in competitor generation reduces the probability that a utility makes a positive transmission investment by 0.5 percentage point. To put this number into perspective, recall that the average investment probability for the entire sample is 62%. Thus, a one standard deviation (15 TWh) increase in competitor generation would reduce a utility's investment probability by 7.5 percentage points, which is a 12% reduction over the base probability. Thus, the impact of competitor generation on investment probability is not only statistically but also economically significant.

Estimates associated with the other variables (load and network size) are all insignificant under the fixed effects specifications, but are significant and of the expected positive sign under the random effects specifications. Sargent-Hansen tests show that when the total line length is used as a measure for the transmission network size, there is no significant difference between the fixed effects and the random effects specifications (columns (1) and (3)). However, when the total line cost is used as a measure for the transmission network size, there is significant difference between the two specifications (columns (2) and (4)). Whether year fixed effects are included or not has only a small effect on the other parameter estimates. Panel B reports estimation results for the same model, using the narrow measure for competitor generation (power purchase only). The results are qualitatively and quantitatively similar to those in panel A.

Hereinafter, we focus on the robust fixed effects specifications. As a sensitivity test, Table 3 reports estimations that include the lagged dependent variable on the right-hand side. The lagged dependent variable is consistently insignificant, suggesting that our results are not subject to significant biases due to the omitted variables problem. Inclusion of the lagged dependent variable also does not affect the other parameter estimates. In particular, competitor generation remains highly significant at the 1%-level, with a slight reduction in its magnitude, while load and network size variables remain insignificant.

Table 4 reports estimation results of a weighted LPM. To ensure that our results are not sensitive to outlier observations, we use load as weights. Competitor generation remains highly significant at the 1%-level, with a small reduction in its magnitude, while load becomes significantly positive at the 10%-level in two of the eight specifications.[19]

6.2 Tobit model

Next, we turn to our Tobit models (11) that utilize the magnitude of investments for estimation. Due to the nonlinear form of the Tobit model, utility-specific effects u_i and year-specific effects α_t cannot be simply differenced out. This poses potential challenges for estimation. An unconditional fixed effects estimation includes these dummy variables directly in the regression model; however, their associated marginal effects will then

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[19] Results are similar when transmission network size is used as weights. These results are not reported here but available upon request.

depend on the observed right-hand side variables. We use this shortcut for year fixed effects α_t only. For the utility-specific effect u_i, we employ two approaches. First, we estimate a random effects specification, thus making a distributional assumption on u_i so that it can be estimated. Second, as a robustness check, we use the semiparametric approach developed in Honoré (1992) to estimate a conditional fixed effects specification.

Table 5 reports panel Tobit estimation results using utility random effects (i.e., the utility-specific term u_i is assumed to be uncorrelated with the right-hand side variables). This is a restrictive assumption and should not be expected to hold in general. However, it allows us to calculate marginal effects without having to rely on the estimates of the utility-specific effects u_i. Using both the broad measure (panel A) and the narrow measure (panel B) for competitor generation, the coefficient estimate on competitor generation is significant at the 1%-level. Depending on model specification, a 1 TWh increase in competitor generation in the wholesale market, holding everything else constant, reduces the latent investment I^*_{it} by 0.74–1.04 miles or by 0.68–0.86 million dollars.

Since we do not observe the latent investment I^*_{it}, we calculate the marginal effects on the observed investment I_{it}. These are reported in Table 6. In each of columns (1)–(4), the first subcolumn contains the marginal effects on the probability of a utility making a positive investment, and the second subcolumn contains the marginal effects on the observed investment magnitude (which is left-censored at zero).[20] Across all model specifications, the marginal effects of competitor generation on investment probability are both qualitatively and quantitatively comparable to our results in the linear probability models. Holding market size and transmission network size constant, a 1 TWh increase in competitor generation reduces the probability of a utility making a positive investment by 0.5–0.7 percentage points, and reduces the observed investment by 0.35–0.49 miles, or 0.30–0.37 million dollars.

Again, as a sensitivity test, Table 7 reports estimation results when lagged dependent variable are included on the right-hand side. The structure of Table 7 mirrors that of Table 5. The lagged dependent variable is consistently insignificant, and its inclusion does not significantly affect the estimates of other parameters. Competitor generation remains significant at 5%-level or above, while all other variables maintain the same significance level as reported in Table 5. All significant estimates show a slight reduction in their magnitudes, compared to those reported in Table 5. These results provide a reasonable degree of assurance that our main results are not subject to significant biases due to omitted variables.

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[20] For example, in column (1) of panel A, the predicted probability of an average utility making a positive investment in a given year is 47%, and a 1 TWh increase in competitor generation reduces the investment probability by 0.5 percentage points. Similarly, for an average utility the predicted value for the observed investment is 22 miles, and a 1 TWh increase in competitor generation reduces the observed investment by 0.35 miles.

Finally, Table 8 reports panel Tobit estimates using a utility fixed effect specification as a further robustness check. Note that the magnitude of the point estimates cannot be easily interpreted, and that we cannot calculate marginal effects free from the estimates of the utility fixed effects u_i. Thus, we focus only on the significance of the parameter estimates. Since fixed effects admit more degrees of freedom, they lead to significantly larger standard errors than those reported in Table 5 (the corresponding random effects specification). When the broad measure for competitor generation is used, competitor generation remains significant in three of four cases, with lower significance levels at 5% or 10%, and becomes insignificant in one case. When the narrow measure is used, competitor generation is only significant at the 10%-level in one of the four cases and becomes insignificant in the remaining three cases.

7 Conclusion

An economy's infrastructure is critical for both its current welfare and its long-term growth. This paper examined private investments in network infrastructure under open access. Using a theoretical model, we have shown that investment incentives under open access can be decomposed into a non-strategic and a strategic part. The non-strategic incentive implies larger network investments in more competitive markets, regardless of their composition. The strategic incentive, on the other hand, depends on market composition and can run in either direction. Using a firm-level dataset of regulated electric utilities, we detected the presence of strategic effects on transmission investments in the U.S. electricity wholesale market. Our results suggest a tradeoff between allocative efficiency in the generation market and transmission infrastructure investments.

As Guthrie (2006) pointed out, we still do not know much about how access regulation affects bottleneck investment in network industries. This paper is a step toward a better understanding of investment incentives under open access, both theoretically and empirically in the context of the U.S. electricity wholesale market. Of course, our estimation results are not necessarily characteristic of the investment incentives in other network industries. Moreover, our dataset does not allow us to uncover the precise mechanism through which variations in market conditions translate into different strategic investment responses. The estimation of a structural model, which identifies the causal relationship between market conditions and investments, requires richer information on competitor characteristics and more accurate measures of network quality. We nevertheless believe that the approach developed in this paper provides a useful framework, which can inform future investigations into the determinants of infrastructure investments under open access.

References

[1] Armstrong, Mark, Chris Doyle, and John Vickers. "The Access Pricing Problem: A Synthesis." *Journal of Industrial Economics* 44 (2), 1996, 131–150.

[2] Barmack, Matthew, Edward Kahn, and Susan Tierney. "A Cost-Benefit Assessment of Wholesale Electricity Restructuring and Competition in New England." *Journal of Regulatory Economics* 31, 2007. 151–184.

[3] Berg, Sandford, and John Tschirhart. *Natural Monopoly Regulation: Principles and Practice*. Cambridge, UK: Cambridge University Press, 1998.

[4] Borenstein, Severin. "The Trouble with Electricity Markets: Understanding California's Restructuring Disaster." *Journal of Economic Perspectives* 16 (1), 2002, 191–211.

[5] Borenstein, Severin and James Bushnell. "An Empirical Analysis of the Potential for Market Power in California's Electricity Industry." *Journal of Industrial Economics* 47 (3), 1999, 285–323.

[6] Borenstein, Severin, James Bushnell, and Frank Wolak. "Measuring Market Inefficiencies in California's Restructured Wholesale Electricity Market." *American Economic Review* 92 (5), 2002, 1376–1405.

[7] Borreau, Marc, Carlo Cambini, and Steffen Hoernig. "My Fibre or Your Fibre? Cooperative Investment, Uncertainty and Access." Working Paper, Nova School of Business and Economics, Lisbon, Portugal.

[8] Brennan, Timothy. "Understanding Raising Rivals' Costs." *Antitrust Bulletin* 33, 1988, 95–114.

[9] Brunekreeft, Gert. "Market-based Investment in Electricity Transmission Networks: Controllable Flow." *Utilities Policy* 12 (4), 2004, 269–281.

[10] Bushnell, James. "Oligopoly Equilibria in Electricity Contract Markets." *Journal of Regulatory Economics* 32, 2007. 225–245.

[11] Bushnell, James, Erin Mansur, and Celeste Saravia. "Vertical Arrangements, Market Structure, and Competition: An Analysis of Restructured U.S. Electricity Markets." *American Economic Review* 98 (1), 2008, 237–266.

[12] Crandall, Robert, Allan Ingraham, and Hal Singer. "Do Unbundling Policies Discourage CLEC Facilities-Based Investment?" *Topics in Economic Analysis & Policy* 4 (1), 2004, Article 14.

[13] Dewenter, Ralf and Justus Haucap (eds.): *Access Pricing: Theory and Practice*. Amsterdam: Elsevier, 2006.

[14] Economides, Nicholas. “The Incentive for Non-Price Discrimination by an Input Monopolist.” *International Journal of Industrial Organization* 16, 1998, 271–284.

[15] Fabrizio, Kira, Nancy Rose, and Catherine Wolfram. “Do Markets Reduce Costs? Assessing the Impact of Regulatory Restructuring on U.S. Electric Generation Efficiency.” *American Economic Review* 97 (4), 2007, 1250–1277.

[16] Foros, Øystein. “Strategic Investments with Spillovers, Vertical Integration and Foreclosure in the Broadband Access Market.” *International Journal of Industrial Organization* 22 (1), 2004, 1–24.

[17] Fowlie, Meredith. “Emissions Trading, Electricity Restructuring, and Investment in Pollution Abatement.” *American Economic Review* 100 (3), 2010, 837–869.

[18] Friederiszick, Hans, Michal Grajek, and Lars-Hendrik Röller. “Analyzing the Relationship between Regulation and Investment in the Telecom Sector.” ESMT White Paper WP-108-01, 2008.

[19] Gans, Joshua and Philip Williams. 1998. “A Primer on Access Regulation and Investment.” In: Margaret Arblaster and Mark Jamison (eds.): *Infrastructure Regulation and Market Reform: Principles and Practice*. Melbourne: ACCC/PURC, 1998.

[20] Gans, Joshua. “Regulating Private Infrastructure Investment: Optimal Pricing for Access to Essential Facilities.” *Journal of Regulatory Economics* 20 (2), 2001, 167–189.

[21] Granitz, Elizabeth and Benjamin Klein. “Monopolization by Raising Rivals’ Costs: The Standard Oil Case.” *Journal of Law and Economics* 29, 1996, 1–48.

[22] Greene, William. *Econometric Analysis (7th Edition)*. Prentice-Hall, 2011.

[23] Guthrie, Graeme, John Small, and Julian Wright.“Pricing Access: Forward versus Backward Looking Cost Rules.” *European Economic Review*, 50 (7), 2006, 1767–1789.

[24] Guthrie, Graeme. “Regulating Infrastructure: The Impact on Risk and Investment.” *Journal of Economic Literature* 44 (4), 2006, 925–972.

[25] Honoré, Bo. “Trimmed LAD and Least Squares Estimation of Truncated and Censored Regression Models With Fixed Effects.” *Econometrica* 60, 1992, 533–565.

[26] Jeon, Doh-Shin and Sjaak Hurkens. “A Retail Benchmarking Approach to Efficient Two-Way Access Pricing: No Termination-Based Priced Discrimination.” *RAND Journal of Economics* 39 (3), 2008, 822–849.

[27] Joskow, Paul and Jean Tirole. “Merchant Transmission Investment.” *Journal of Industrial Economics* 53 (2), 2005, 233–264.

[28] Kleit, Andrew and Dek Tecrell. “Measuring Potential Efficiency Gains from Deregulation of Electricity Generation: A Bayesian Approach.” *Review of Economics and Statistics* 83 (3), 2001, 523–530.

[29] Klumpp, Tilman and Xuejuan Su. “Open Access and Dynamic Efficiency.” *American Economic Journal: Microeconomics* 2 (2), 2010, 64–96.

[30] Krattenmaker, Thomas and Steven Salop. “Anticompetitive Exclusion: Raising Rivals’ Costs to Achieve Power over Price.” *Yale Law Journal* 96, 1986, 209–294.

[31] Laffont, Jean-Jacques, and Jean Tirole. *Competition in Telecommunications (The Munich Lectures in Economics)*. Cambridge, MA: MIT Press, 2000.

[32] Mansur, Erin. “Upstream Competition and Vertical Integration in Electricity Markets.” *Journal of Law and Economics* 50 (1), 2007, 125–156.

[33] Salop, Steven and David Scheffman. “Raising Rivals’ Costs.” *American Economic Review* 73, 1983, 267–271.

[34] Salop, Steven and David Scheffman. “Cost-Raising Strategies.” *Journal of Industrial Economics* 36, 1987, 19–34.

[35] Sidak, Gregory, and Daniel Spulber. “Deregulatory Takings and Breach of the Regulatory Contract.” *New York University Law Review* 71 (4), 1996, 851–999.

[36] Valletti, Tommaso, and Carlo Cambini. “Investments and Network Competition.” *RAND Journal of Economics* 36 (2), 2005, 446–467.

[37] Vogelsang, Ingo. “Price Regulation for Independent Transmission Companies.” *Journal of Regulatory Economics* 20 (2), 2001, 141–165.

[38] Vogelsang, Ingo. “Price Regulation of Access to Telecommunications Networks.” *Journal of Economic Literature* 41 (3), 2003, 830–862.

[39] Wolak, Frank. "Measuring Unilateral Market Power in Wholesale Electricity Markets: The California Market, 1998–2000." *American Economic Review (Papers and Proceedings)* 93 (2), 2003, 425–430.

[40] Wooldridge, Jeffrey. *Econometric Analysis of Cross Section and Panel Data (2nd Edition)*. Cambridge, MA: MIT Press, 2010.

[41] Zhang, Fan. "Does Electricity Restructuring Work? Evidence from the U.S. Nuclear Energy Industry." *Journal of Industrial Economics* 55 (3), 2007, 397–418.

Table 1: Summary statistics (858 observations) and sample selection

Variable		Mean	Std. Dev.	Min.	Max.
Investment					
New line length	(miles)	18.06	43.07	−64.45	499.45
New line cost	($ mil.)	11.15	33.89	−3.67	639.61
Investment probability		0.62	0.48	0	1
Network size					
Total line length	(100 miles)	33.37	32.07	0.46	186.50
Total line cost	($10 mil.)	40.11	43.40	0.13	273.12
Market size					
Total energy	(TWh)	28.17	25.82	0.32	185.45
Load	(TWh)	20.45	20.35	0.16	105.27
Market composition					
Own generation	(TWh)	17.12	18.07	0.03	89.44
Power purchase	(TWh)	9.39	12.48	0.05	159.05
Wheeling in	(TWh)	4.21	6.19	0.00	43.45
Wheeling out	(TWh)	4.11	6.12	−0.48	43.25
Purchase + wheeling in	(TWh)	13.60	15.16	0.12	168.21

		Sample selection		
Annual average		Selected subsample	All Form 1 observations	% in sample
New line length	(miles)	1,408	2,571	54.8
New line cost	($ mil.)	869	1,339	64.9
Total line length	(100 miles)	2,603	3,902	66.7
Total line cost	($10 mil.)	3,058	4,405	69.4
Total energy	(TWh)	2,197	3,275	67.1
Load	(TWh)	1,595	2,415	66.1
Own generation	(TWh)	1,336	1,664	80.3
Power purchase	(TWh)	733	1,427	51.4
Wheeling-in	(TWh)	328	547	60.0
Wheeling-out	(TWh)	321	518	61.9
Purchase + wheeling-in	(TWh)	1,061	1,973	53.8

Table 2: Linear probability model (LPM), using utility fixed and random effects

$I(\text{Invest} > 0)$	(1)		(2)		(3)		(4)	
	FE	RE	FE	RE	FE	RE	FE	RE
A. Broad measure: Competitor generation = power purchase + wheeling-in								
Competitor generation	$-.0051^{***}$	$-.0052^{***}$	$-.0051^{***}$	$-.0050^{***}$	$-.0046^{***}$	$-.0048^{***}$	$-.0046^{***}$	$-.0046^{***}$
	(.0007)	(.0008)	(.0007)	(.0008)	(.0008)	(.0008)	(.0008)	(.0008)
Load	.0032	$.0069^{***}$	.0011	$.0055^{***}$	.0006	$.0067^{***}$	.0028	$.0060^{***}$
	(.0043)	(.0017)	(.0057)	(.0021)	(.0048)	(.0018)	(.0056)	(.0020)
Total line length	.0003	$.0028^{***}$			$-.0002$	$.0026^{**}$		
	(.0026)	(.0011)			(.0025)	(.0012)		
Total line cost			.0007	$.0024^{***}$			$-.0014$	$.0019^{**}$
			(.0013)	(.0009)			(.0015)	(.0009)
Year fixed effects	No		No		Yes		Yes	
Sargent-Hansen p-value	.5343		.0147		.4722		.0061	
B. Narrow measure: Competitor generation = power purchase only								
Competitor generation	$-.0052^{***}$	$-.0055^{***}$	$-.0051^{***}$	$-.0054^{***}$	$-.0044^{***}$	$-.0049^{***}$	$-.0044^{***}$	$-.0049^{***}$
	(.0006)	(.0007)	(.0006)	(.0006)	(.0008)	(.0008)	(.0008)	(.0008)
Load	.0031	$.0065^{***}$	.0019	$.0051^{**}$	.0005	$.0063^{***}$	.0025	$.0057^{***}$
	(.0043)	(.0017)	(.0057)	(.0021)	(.0048)	(.0018)	(.0056)	(.0020)
Total line length	.0001	$.0025^{**}$			$-.0004$	$.0024^{**}$		
	(.0025)	(.0011)			(.0025)	(.0012)		
Total line cost			.0006	$.0023^{**}$			$-.0014$	$.0018^{**}$
			(.0013)	(.0009)			(.0015)	(.0009)
Year fixed effects	No		No		Yes		Yes	
Sargent-Hansen p-value	.5379		.0254		.4789		.0128	

Notes: Standard errors (in parentheses) are clustered by utilities. * significant at 10%; ** significant at 5%; *** significant at 1%.

Table 3: Dynamic LPM (using utility fixed effects)

$I(\text{Invest} > 0)$	*A. Broad measure*				*B. Narrow measure*			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Lagged $I(\text{Invest} > 0)$	.0711	.0706	.0636	.0640	.0729	.0723	.0659	.06636
	(.0466)	(.0467)	(.0458)	(.0458)	(.0466)	(.0467)	(.0457)	(.0457)
Competitor generation	$-.0047^{***}$	$-.0047^{***}$	$-.0042^{***}$	$-.0043^{***}$	$-.0048^{***}$	$-.0047^{***}$	$-.0041^{***}$	$-.0041^{***}$
	(.0007)	(.0007)	(.0008)	(.0008)	(.0006)	(.0006)	(.0008)	(.0008)
Load	.0029	.0020	.0005	.0027	.0027	.0018	.0004	.0024
	(.0040)	(.0054)	(.0045)	(.0054)	(.0040)	(.0054)	(.0045)	(.0053)
Total line length	.0002		−.0003		.0000		−.0005	
	(.0025)		(.0024)		(.0024)		(.0024)	
Total line cost		.0005		−.0015		.0005		−.0014
		(.0012)		(.0014)		(.0012)		(.0015)
Year fixed effects	No	No	Yes	Yes	No	No	Yes	Yes

Notes: Standard errors (in parentheses) are clustered by utilities. * significant at 10%; ** significant at 5%; *** significant at 1%.

Table 4: Weighted LPM with weights = load (using utility fixed effects)

I(Invest > 0)	A. *Broad measure*				B. *Narrow measure*			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Competitor generation	$-.0047^{***}$	$-.0046^{***}$	$-.0041^{***}$	$-.0040^{***}$	$-.0045^{***}$	$-.0045^{***}$	$-.0036^{***}$	$-.0036^{***}$
	(.0008)	(.0008)	(.0008)	(.0008)	(.0007)	(.0008)	(.0009)	(.0009)
Load	$.0041^{*}$	.0011	−.0001	−.0012	$.0039^{*}$	.0012	−.0013	−.0014
	(.0021)	(.0029)	(.0035)	(.0037)	(.0020)	(.0030)	(.0036)	(.0039)
Total line length	−.0029		−.0035		−.0023		−.0029	
	(.0026)		(.0026)		(.0027)		(.0027)	
Total line cost		.0007		−.0012		.0007		−.0011
		(.0008)		(.0011)		(.0007)		(.0011)
Year fixed effects	No	No	Yes	Yes	No	No	Yes	Yes

Notes: Standard errors (in parentheses) are clustered by utilities. * significant at 10%; ** significant at 5%; *** significant at 1%.

Table 5: Panel Tobit models (using utility random effects)

New line length / cost	*A. Broad measure*				*B. Narrow measure*			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Competitor generation	$-.7588^{**}$	$-.8603^{***}$	$-.7380^{**}$	$-.7386^{***}$	-1.0440^{***}	$-.8406^{***}$	$-.9978^{**}$	$-.6842^{**}$
	(.3054)	(.2550)	(.3131)	(.2519)	(.3910)	(.2969)	(.3968)	(.2894)
Load	$.8640^{***}$	$-.1239$	$.8063^{***}$	.1061	$.8496^{***}$	$-.1812$	$.7919^{***}$	.0485
	(.2774)	(.2558)	(.2772)	(.2609)	(.2718)	(.2514)	(.2711)	(.2553)
Total line length	$.5528^{***}$		$.5609^{***}$		$.5447^{***}$		$.5507^{***}$	
	(.1717)		(.1715)		(.1688)		(.1683)	
Total line cost		$.8749^{***}$		$.7015^{***}$		$.8344^{***}$		$.6656^{***}$
		(.1250)		(.1291)		(.1226)		(.1264)
Year fixed effects	No	No	Yes	Yes	No	No	Yes	Yes

Notes: Dependent variable is new line length (cost) when right-hand side variable for network size is total line length (cost). Year dummies are used to capture unconditional year fixed effects. Standard errors are calculated using the observed information matrix. * significant at 10%; ** significant at 5%; *** significant at 1%.

Table 6: Panel Tobit model marginal effects (using utility random effects)

Predicted outcome	(1)		(2)		(3)		(4)	
	$Pr(I>0)$	$E(I)$	$Pr(I>0)$	$E(I)$	$Pr(I>0)$	$E(I)$	$Pr(I>0)$	$E(I)$
A. Broad measure								
Competitor generation	$-.0049^{**}$	$-.3543^{**}$	$-.0074^{***}$	$-.3706^{***}$	$-.0048^{**}$	$-.3446^{**}$	$-.0065^{***}$	$-.3185^{***}$
	(.0020)	(.1428)	(.0022)	(.1104)	(.0020)	(.0015)	(.0022)	(.1088)
Load	$.0056^{***}$	$.4034^{***}$	$-.0011$	$-.0534$	$.0052^{***}$	$.3765^{***}$	.0009	.0457
	(.0018)	(.1306)	(.0022)	(.1103)	(.0018)	(.1304)	(.0023)	(.1124)
Total line length	$.0036^{***}$	$.2581^{***}$			$.0036^{***}$	$.2619^{***}$		
	(.0011)	(.0808)			(.0011)	(.0808)		
Total line cost			$.0075^{***}$	$.3770^{***}$			$.0061^{***}$	$.3025^{***}$
			(.0011)	(.0570)			(.0011)	(.0577)
Year fixed effects	No		No		Yes		Yes	
Predicted value	.4668	22.11	.4308	14.58	.4669	21.93	.4312	14.30
B. Narrow measure								
Competitor generation	$-.0068^{***}$	$-.4865^{***}$	$-.0072^{***}$	$-.3622^{***}$	$-.0065^{**}$	$-.4652^{**}$	$-.0060^{**}$	$-.2953^{**}$
	(.0025)	(.1821)	(.0025)	(.1279)	(.0026)	(.1847)	(.0025)	(.1247)
Load	$.0055^{***}$	$.3959^{***}$	$-.0016$	$-.0781$	$.0052^{***}$	$.3692^{***}$	.0004	.0209
	(.0018)	(.1276)	(.0022)	(.1084)	(.0018)	(.1272)	(.0022)	(.1101)
Total line length	$.0035^{***}$	$.2538^{***}$			$.0036^{***}$	$.2567^{***}$		
	(.0011)	(.0792)			(.0011)	(.0791)		
Total line cost			$.0072^{***}$	$.3595^{***}$			$.0058^{***}$	$.2872^{***}$
			(.0010)	(.0556)			(.0011)	(.0564)
Year fixed effects	No		No		Yes		Yes	
Predicted value	.4660	21.97	.4308	14.57	.4662	21.80	.4315	14.30

Notes: Dependent variable is new line length (cost) when right-hand side variable for network size is total line length (cost). Year dummies are used to capture unconditional year fixed effects. Standard errors are calculated using the observed information matrix. * significant at 10%; ** significant at 5%; *** significant at 1%.

Table 7: Dynamic panel Tobit model (using utility random effects)

New line length / cost	*A. Broad measure*				*B. Narrow measure*			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Lagged new line length	.0885 (.0539)		.0780 (.0545)		.0860 (.0540)		.0768 (.0545)	
Lagged new line cost		.0872 (.0901)		.0713 (.0895)		.1067 (.0901)		.0897 (.0895)
Competitor generation	−.7385** (.2992)	−.8210*** (.2517)	−.7190** (.3072)	−.7095*** (.2496)	−1.0028*** (.3794)	−.8060*** (.2905)	−.9649** (.3867)	−.6644** (.2854)
Load	.8192*** (.2674)	−.1003 (.2500)	.7720*** (.2682)	.1105 (.2561)	.8028*** (.2619)	−.1478 (.2453)	.7561*** (.2621)	.0597 (.2503)
Total line length	.5333*** (.1652)		.5423*** (.1659)		.5250*** (.1624)		.5322*** (.1627)	
Total line cost		.8253*** (.1316)		.6703*** (.1335)		.7765*** (.1278)		.6291*** (.1294)
Year fixed effects	No	No	Yes	Yes	No	No	Yes	Yes

Notes: Dependent variable is new line length (cost) when right-hand side variable for network size is total line length (cost). Year dummies are used to capture unconditional year fixed effects. Standard errors are calculated using the observed information matrix. * significant at 10%; ** significant at 5%; *** significant at 1%.

Table 8: Panel Tobit model, using utility fixed effects

New line length / cost	*A. Broad measure*				*B. Narrow measure*			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Competitor generation	−1.5823*	−4.2567**	−1.8363	−3.7547**	−2.5093*	−6.5825	−2.1459	−4.4508
	(.9052)	(1.8353)	(1.3910)	(1.6441)	(1.3718)	(4.1011)	(2.0858)	(3.0179)
Load	3.9858	4.0112	2.4760	4.3669**	4.4386	4.9028	2.8368	4.4009
	(3.5548)	(3.8130)	(2.3532)	(2.2220)	(3.2454)	(4.3409)	(2.7799)	(3.7253)
Total line length	−2.3614		−2.6885		−2.2338		−2.2755	
	(4.0747)		(4.5999)		(4.4503)		(5.4851)	
Total line cost		1.9080		.2606		1.8347		.5171
		(1.7606)		(1.7052)		(1.5712)		(1.4417)
Year fixed effects	No	No	Yes	Yes	No	No	Yes	Yes

Notes: Dependent variable is new line length (cost) when right-hand side variable for network size is total line length (cost). Year dummies are used to capture unconditional year fixed effects. Standard errors are calculated using bootstrap. * significant at 10%; ** significant at 5%; *** significant at 1%.