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Abstract

We examine the incentives of access-regulated firms to invest in infrastructure facilities they must share with competitors. The non-strategic incentives imply that investment depends positively on the 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

[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.

in the same or 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 incumbents' 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 power generation. We also find that, after controlling for total generation, 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.

[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. Moreoever, the strategic effect can strengthen the non-strategic effect. This occurs if the network operator uses network investments as a (legal) means to raise its rivals' production costs in the competitive segment, by exploiting the fact that higher investments translate to higher access fees (and hence higher marginal costs for competitors). This possibility still exists in our current framework, and is demonstrated in Section 3.3 below.

[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.

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 infrastructre investments with competitors 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, where we estimate a model of network investment and discuss our estimation results. Section 6 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 no 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. Indeed, in a survey Guthrie (2006) laments:

> "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 first step toward filling this gap.

3 Theoretical Model

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 to end users. 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), which can provide an unlimited amount of network services at zero marginal costs.[4]

3.1 Open access regulation

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 network 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 $P_{\theta Q} \geq -P_\theta / Q$. The last assumption implies that, as the total quantity Q increases, the marginal impact of θ on consumers' willingness-to-pay does not decrease too much.[5]

[4]This assumption obviously holds within bounds only, as networks become congested when heavily used. The problem of congestion is especially important for our empirical application, which concerns electric transmission grids. We will discuss how congestion concerns affect the model's suitability for our empirical analysis in Section 4.1.

[5]This assumption is automatically satisfied for any demand function with $P_{\theta Q} \geq 0$, which includes many commonly used demand functions such as $P(\theta, Q) = a\theta - G(Q)$ (an increase in θ leads to a parallel shift of the demand function outward) and $P(\theta, Q) = a - G(Q)/\theta$ (an increase in θ leads to a horizontal stretch of the demand function without affecting the maximum willingness-to-pay), for any $G'(Q) > 0$.

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 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 ($i=0,\ldots,n$). We use

$$Q \;=\; Q_0 + Q_1 + \ldots + Q_n$$

to denote the combined quantity of all firms. Firm i's cost of producing Q_i units of the final good is $C_i(Q_i)$, with $C_i' \geq 0$.

Under open access regulation, the incumbent is required to lease its essential facilities to competitors, at a regulated tariff. The access tariff must meet the standards of being *Fair, Reasonable, and Non-Discriminatory (FRAND)*.[6] This requirement will be formally modelled as follows.

Consider a tariff $T:\mathbb{R}_+ \to \mathbb{R}$ that maps firm i's production quantity Q_i into a total 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,

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

for all i (including the incumbent).

The tariff T may be a linear tariff, i.e., $T(Q_i)=a\cdot Q_i$ (the case explored in Klumpp and Su 2010); or a non-linear tariff (e.g., a lump-sum transfer or two-part tariff). In any case, under (1), 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, meaning that leasing the network to downstream producers cannot, by itself, be a source of profit.[7]

[6]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)).

[7]As usual, a zero profit is a normalization. A "normal profit," which compensates the incumbent for the opportunity cost of its investment, can easily be folded into the investment cost $F(\theta)$.

3.2 Downstream competition

With open access to the incumbent's essential facilities, an entrant pays two types of variable costs: the production cost $C_i(Q_i)$ and the access cost $T(Q_i)$. Unless $T' = 0$ (a lump-sum transfer from the entrants to the incumbents), an entrant's marginal cost of accessing the network becomes part of its overall marginal cost of operating in the market. Assuming all other firms produce their equilibrium quantities, entrant i's profit function under open access is given by

$$\pi_i(Q_i) \ = \ Q_i P(\theta, Q_i + Q^*_{-i}) - C(Q_i) - T(Q_i). \tag{2}$$

Entrant i's own equilibrium quantity, Q_i^*, must therefore satisfy the first-order condition

$$\frac{\partial}{\partial Q_i}\pi_i \ = \ Q_i^* P_Q(\theta, Q^*) + P(\theta, Q^*) - C'(Q_i^*) - T'(Q_i^*) \ = \ 0. \tag{3}$$

On the other hand, assuming all entrants produce their equilibrium quantities, the incumbent's profit function under open access is given by

$$\pi_0(\theta, Q_0) \ = \ Q_0 P(\theta, Q_0 + Q^*_{-0}) \ - \ C_0(Q_0) + \ \sum_{i=1}^{n} T(Q_i^*) \ - \ F(\theta). \tag{4}$$

Observe that the payment $T(Q_0)$ does not affect the integrated incumbent's profit: $T(Q_0)$ is both a cost and a revenue component for the integrated firm (it is an internal transfer payment), and thus does not appear in (4). Unlike the entrants, therefore, the incumbent does not treat the access tariff as a *variable* cost. At the downstream competition stage, the incumbent takes its upstream investment in θ, and hence, $F(\theta)$ as given. The incumbent's downstream quantity Q_0^* is thus characterized by the first-order condition

$$\frac{\partial}{\partial Q_0}\pi_0 \ = \ Q_0^* P_Q(\theta, Q^*) + P(\theta, Q^*) - C_0'(Q_0^*) \ = \ 0. \tag{5}$$

Comparing (5) and (3), we see that T' only affects the entrants' marginal costs, but not the incumbent's. The internal transfer payment $T(Q_0^*)$ still enters the incumbent's equilibrium profit, but as a fixed cost—namely, the remainder of the investment $F(\theta)$ that is not collected as access fees from the entrants in equilibrium. To see this, use the FRAND principle (1) to express the last two terms in the incumbent's profit (4) as

$$F(\theta) - \sum_{i=1}^{n} T(Q_i^*) = \Big(1 - \sum_{i=1}^{n} \gamma_i^*\Big) F(\theta) = \gamma_0^* \cdot F(\theta) = T(Q_0^*). \tag{6}$$

Thus, the incumbent's *equilibrium* profit can be written in a manner symmetric to an entrant's profit in (2). However, the same is not true for the incumbent's profit *function*: Unless T is lump-sum, the presence of T in the entrants' (but not the incumbent's) variable costs confers a competitive advantage to the incumbent in the downstream market. It is precisely for this reason that the incumbent can use its network investment as a strategic tool to raise the entrants' marginal costs relative to its own.[8] We will discuss the strategic value of upstream investments in the next section.

3.3 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. Using (6), therefore, the first-order condition for a maximum of π_0 with respect to upstream quality θ is given by

$$\begin{aligned} \frac{d}{d\theta}\pi_0 \;=\; & Q_0^*\left[P_\theta(\theta,Q^*)+P_Q(\theta,Q^*)\frac{dQ^*}{d\theta}\right] + \frac{dQ_0^*}{d\theta}P(\theta,Q^*) \\ & - \frac{dQ_0^*}{d\theta}C_0'(Q_0^*) - \gamma_0^* F'(\theta) - \frac{d\gamma_0^*}{d\theta}F(\theta) \;=\; 0. \qquad (7) \end{aligned}$$

Further substituting the incumbent's own downstream first-order condition (5) into (7), and rearranging, the upstream first-order condition can be expressed as follows:

$$\underbrace{Q_0^* P_\theta(\theta,Q^*)}_{\substack{\text{Non-strategic} \\ \text{revenue effect}}} \;+\; \underbrace{Q_0^* P_Q(\theta,Q^*)\frac{dQ_{-0}^*}{d\theta}}_{\substack{\text{Strategic} \\ \text{revenue effect}}} \;=\; \underbrace{\gamma_0^* F'(\theta)}_{\substack{\text{Non-strategic} \\ \text{cost effect}}} \;+\; \underbrace{\frac{d\gamma_0^*}{d\theta}F(\theta)}_{\substack{\text{Strategic} \\ \text{cost effect}}}. \qquad (8)$$

Non-strategic effects. What we call non-strategic effects are those components of (8) that do not depend on the adjustment of downstream quantities in response to changes in upstream quality. Thus, if we neglect the impact of investments on downstream outcomes, the incumbent's optimal investment will be characterized by equality of the non-

[8] 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. In Klumpp and Su (2010), we provide conditions under which the "raising rivals' cost" effect perversely amplifies investments beyond the socially optimal level.

strategic cost and revenue effects. Since $Q_0^* = \gamma_0^* Q^*$, we can express this equality as follows:

$$\gamma_0^* Q^* P_\theta(\theta, Q^*) = \gamma_0^* F'(\theta) \quad \Leftrightarrow \quad Q^* P_\theta(\theta, Q^*) = F'(\theta). \tag{9}$$

It is easy to check that the right side of (9) is the same as the optimality condition on θ if the incumbent were an unregulated monopoly in both the upstream and the downstream market. In this case, at the optimal downstream monopoly quantity Q^* the envelope theorem applies, and the optimal choice of θ will be determined by equating the marginal benefit of quality and the marginal cost of quality. Thus, looking at the non-strategic effects alone, the incumbent behaves just like a monopolist in the vertically integrated market, with no strategic interaction entering this part of its investment incentives.

Implicitly differentiating both sides of (9) with respect to Q^*, we have

$$\frac{d\theta}{dQ^*} = \frac{P_\theta(\theta, Q^*) + Q^* P_{\theta Q}(\theta, Q^*)}{F''(\theta) - Q^* P_{\theta\theta}(\theta, Q^*)} \geq 0. \tag{10}$$

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 source of the increase in Q^*—be it an exogenous demand shock, a cost reduction by the incumbent, a cost reduction by an existing competitor, or entry of new competitors.

Strategic effects. In response to a change in quality θ and associated investment cost $F(\theta)$, the regulated access tariff T must adjust in order to continue to satisfy the FRAND principle. Since T is a variable downstream cost component for the entrants, the downstream Cournot quantities $Q_1^*, \ldots, Q_n^*$ will in turn adjust, and so will the firms' market shares (including the incumbent's). 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 share gives rise to strategic effects in the investment decision. Consider first the strategic revenue term in (8). Since demand is downward sloping, if $dQ_{-0}^*/d\theta$ is positive the strategic revenue effect weakens the incumbent's incentive to invest. On the other hand, if $dQ_{-0}^*/d\theta$ is negative, the incentive to invest is strengthened. This is the case whenever the slope of the access tariff, T', increases sufficiently as a result of the investment to reduce the entrants' combined quantity. In this situation, the incumbent can use network investments strategically to raise its rivals' costs. Similarly, if $d\gamma_0^*/d\theta$ is positive the strategic cost term in (8) weakens the investment incentive, and if $dg_0^*/d\theta$ is negative it strengthens them.

Unlike the non-strategic effects, one generally cannot sign these strategic effects unless simplifying assumptions are made. For example, in Klumpp and Su (2010) we consider the case of symmetric linear downstream cost functions (normalized to zero), linear demand, and linear access pricing (i.e., $T(Q_i) = aQ_i$). Under these assumptions, one can derive conditions on the investment cost function F for the strategic effect to increase θ above the level implied by the non-strategic effects alone.[9] Relaxing one or more of these assumptions, one can still solve the model numerically to assess the direction and strength of the strategic investment incentive. For example, if the incumbent has a higher downstream marginal cost than the entrants—a plausible assumption in the electricity generation industry—the strategic effects reduce θ if the number of firms is sufficiently large, and can become strong enough to result in a zero investment (i.e., a market shutdown).

Despite the difficulties involved in evaluating these strategic effects, their presence is empirically testable. Suppose we observe output and investment data in a network industry governed by FRAND open-access regulation. If, after controlling for the market size (Q^*), investment depends on market composition (Q^*_{-0} vs. Q^*_0), then the incumbent must have taken the strategic revenue and strategic cost terms into consideration. Moreover, the strength and direction of this dependence can then be compared to the non-strategic effect, given by the relationship between market size and investment. In the next two sections, we will demonstrate how this can be done, using data from the U.S. electricity wholesale market.

4 The U.S. Electricity Wholesale Market

Our aim is to empirically test for the presence of strategic investment incentives using data from 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. Our empirical tests are presented in the next section.

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 transmis-

[9] More precisely, in Klumpp and Su (2010) we show that $F(\theta^S) < (\theta^S)^2/[2(1+\sqrt{2})]$ (where θ^S is the socially optimal investment level) is sufficient for the incumbent's investment to exceed θ^S. This, in turn, can be shown to imply a positive sign for the strategic effect.

sion 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."[10] 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.[11]

In accordance with our model, we regard transmission as the upstream (bottleneck) segment of the wholesale market, and generation as the downstream segment. Unlike the upstream network in our model, however, the electricity transmission grid is not a pure public good and can become congested when the power flow on a certain transmission line exceeds its capacity. To prevent congestion, system operators may either ration access to the grid or include a location-based component in the access rate. Actual access rates to the transmission grid are hence dependent on a variety of factors excluded from our model.[12] Nevertheless, while FERC allows transmission pricing to be flexible to reflect congestion concerns, it uses the rates, terms, and conditions of a utility's 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.[13] 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.

Demand for wholesale power comes from electricity retailers that distribute power to final customers. As local utilities have traditionally been monopoly providers of retail services, they have also been monopsony buyers of wholesale power. Recently, however, a number of states have liberalized their electricity retail markets as well, allowing competing retailers to service customers and thus to buy electricity in the same wholesale

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

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

[12] 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).

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

market. Our theoretical model bypasses the precise structure of the retail market and simply assumes a downward sloping demand curve for the final good. This assumption is justified as long as the demand side does not discriminate among suppliers. In fact, when the local utility is the monopsony buyer of wholesale power, it is subject to retail regulations that impose a fiduciary duty on the retailer to employ a minimum cost combination of its own generation and wholesale purchases of competitor generation. On the other hand, when there are multiple competing retailers, profit maximization prevents these firms from purchasing power from more expensive sources when cheaper alternatives are available. Thus, the assumption of a downward-sloping demand curve in our theoretical model can be reconciled with actual procurement practices in the electricity retail market.

4.2 Data

We use annual FERC Form 1 data for our empirical analysis. FERC 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. In total, we have annual data on 78 utilities 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 in two ways: Physical, i.e., the length of new or existing transmission lines, and monetary, i.e., 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 (e.g., 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 (which could be different for otherwise identical lines installed in different years). Finally, there are a few instances where positive values for the length measure are reported, but zero or missing values for the cost measure, indicating potential measurement errors. For robustness, we use both physical and monetary measures in our analysis.[14]

Power generation and disposition. Form 1 reports an energy balance sheet for each utility, containing energy generation on one side and energy disposition on the other.

[14]The correlation coefficient between physical and monetary investment measures is 0.46. The correlation coefficient between physical and monetary asset measures is 0.84.

On the generation side, total energy is either generated by the utility itself or by its competitors. On average, a utility generates about two thirds of its total energy, while its competitors generate about one third. 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 the total energy. Generation and usage data capture the size as well as the composition of the electricity wholesale market.

Not all vertically integrated utilities have a complete reporting history for the period 2000–2010: Some were initially active but ceased operation during the sample period. Others were initially integrated and later divested either their transmission or their generation business. Yet others experienced changes in their corporate structure, with several utilities merging into one, or one utility splitting into several. We eliminate utilities that do not have a complete reporting history from our dataset, and instead focus on those that operated in a business-as-usual fashion for the entire sample period.[15] This leaves us with our sample of 78 utilities, resulting in a total number of 858 observations of annual investments, transmission assets, and energy account variables. Summary statistics of these variables are reported in Table 1.

5 Empirical Analysis

5.1 Regression models of network investment

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.[16] 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

[15]To see why our business-as-usual restriction is important, consider the case of Montana Power Company, which 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. It is very likely that this firm's investment decisions were governed by considerations different from those of a typical utility.

[16]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.

investments could not have been based on the strategic incentives explored in our theoretical analysis.) Thus, in order to capture investment incentives under open-access regulation and wholesale competition, we use annual transmission investments during the period 2000–2010 as our dependent variable.

A challenge arises because 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.[17] On the other hand, our dataset contains a large fraction of zero entries for these variables: Approximately 41% of the observations in our sample have a zero entry for new line length, and 42% have a zero entry for new line cost. Ignoring this censoring feature and using a linear model of transmission investments would bias the estimates toward zero.

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 1 if investment is positive, and 0 otherwise, and estimate the probability of a utility making a positive investment decision (regardless of whether the investment is large or small). By ignoring the magnitude of investments, this approach offers a robust, but less efficient, estimate of the underlying parameters governing utilities' investment decision. Second, we estimate a panel structure Tobit model, which utilizes both the probability of investments and variation in the magnitude of observed positive investments. If the model is not misspecified, this approach offers a more efficient estimate of the underlying parameters, but it is less robust to misspecification errors.

More specifically, consider a latent variable I^*_{it} 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

$$I^*_{it} \;=\; u_i + \beta_1\,\mathrm{COMPGEN}_{i,t-1} + \beta_2\,\mathrm{MARKET}_{i,t-1} + \beta_3\,\mathrm{NETWORK}_{i,t-1} + \varepsilon_{it}. \quad (11)$$

In (11), for utility i and year t, $\mathrm{COMPGEN}_{i,t-1}$ denotes its competitors' generation of total energy in the previous year (i.e., year $t-1$). $\mathrm{MARKET}_{i,t-1}$ is the utility's total market size in the previous year, part of which consists of the utility's own generation, and part of which consists of the combined generation of competitors. $\mathrm{NETWORK}_{i,t-1}$ is the existing value of total transmission assets at the beginning of year t (i.e., end of

[17] Out of 858 observations in our dataset, only eleven observations contain a negative value for the 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.

year $t-1$), before the present year's investment. u_i is a time-invariant utility-specific effect, and ε_{it} is the error term.

In the binary case, we transform the observed investment into a discrete outcome variable I_{it} as follows:

$$I_{it} = \begin{cases} 1 & \text{if } I_{it}^* > 0, \\ 0 & \text{otherwise.} \end{cases} \tag{12}$$

For our Tobit estimation, we transform the observed investment into a continuous outcome variable I_{it} as follows:

$$I_{it} = \begin{cases} I_{it}^* & \text{if } I_{it}^* > 0, \\ 0 & \text{otherwise.} \end{cases} \tag{13}$$

Of course, transmission investment also depends on many other factors not explicitly included in the right-hand side of (11), such as population density of the service area, the availability of natural resources used in generation, the political environment, etc. 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., $\text{COMPGEN}_{i,t-1}$, $\text{MARKET}_{i,t-1}$, $\text{NETWORK}_{i,t-1}$), they are captured by the error term ε_{it} and do not bias our parameter estimates. However, if these factors varied over time and their variation was somehow correlated with our explanatory variables, they would pose an omitted variable problem that could bias our estimates.

5.2 Hypotheses

Note that, in our theoretical model, both the upstream investment decision and the downstream market competition outcome are simultaneously determined in the equilibrium. In this sense, the causal relationship between investment decisions and market outcomes runs both ways: An upstream investment affects the access rate 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.

Since our primary objective is to investigate the determinants of upstream investments, our empirical analysis focuses on only one direction of this causal relationship: The effects of downstream competition on upstream investments. This is achieved by using lagged variables on the right-hand side of (11) as our explanatory variables. The lagged variables are predetermined when the utility makes its current investment decision. Thus, even though upstream investment decisions do affect contemporaneous outcomes in the downstream market, they do not affect earlier market outcomes. We therefore interpret our coefficient as representing a causal relationship between downstream market outcomes and upstream investments, in the sense of Granger causality.

Our theoretical model predicts that, without strategic considerations, network investment depends on the downstream market size (Q^*) but not on the composition of the downstream market (Q^*_{-0} vs. Q^*_0). With strategic considerations, on the other hand, network investment depends on the downstream market composition *after controlling for market size*. Thus, by using lagged outcomes as instruments for contemporaneous outcomes, our main focus is on the parameter β_1 in our regression model (11). An estimate of β_1 significantly different from zero would then support our theoretical claim—namely, that access-regulated utilities do take strategic implications of their investments on their competitors' behavior into account when deciding on their investments. Moreover, if the estimate of β_1 is significantly different from zero, its sign can tell us whether the strategic investment incentive strengthens or weakens the non-strategic investment incentive.

5.3 Estimation results and interpretation

We estimate the binary choice model using linear probability, Probit, and Logit specifications. We begin with the panel structure linear probability model (LPM). Despite the shortcoming that the LPM does not restrict predicted probabilities to lie between 0 and 1, its estimates are nonetheless consistent. Furthermore, the linear specification allows us to perform Hausman tests between fixed effect and random effect models. (The Hausman test results will then be used for choosing appropriate specifications for our non-linear models.)

Estimation results for the LPM are reported in Table 2. The dependent variable is binary, indicating whether utility i makes a positive investment in year t or not. Among the explanatory variables, the regressions reported in Table 2 all use competitor generation as a measure of market composition, but differ in the measures used for market size and existing transmission assets. In each of columns (1)–(4), we compare a fixed effect and a random effect specification of the model. In all four cases, the Hausman test fails to reject the null hypothesis of no systematic difference between the fixed effect and random effect specifications. Since the latter gives more efficient estimates, we focus our discussion on the random effect results. The estimates indicate that the probability of a utility making a positive investment in a given year depends significantly and positively on both downstream market size and on transmission network size (at the 10% level or below). Investment probability depends significantly and negatively on competitors' presence in the downstream market (at the 1% level): Holding market size and initial network size constant, for every TWh increase in competitors' generation in the previous year, the probability of the utility making a positive investment in its transmission network decreases by 0.5–0.9%.[18]

Table 3 reports estimation results for panel structure Probit and Logit models. For both, we adopt the random effect specification.[19] All estimates are of the expected sign, and the estimate for the coefficient on competitor generation is always significantly negative. The reported marginal effects suggest that, holding downstream market size and the initial transmission network size constant, every TWh increase in competitors' presence in the downstream market reduces the probability of investment by 0.8–1.6%.

We now turn to our continuous outcome variable. Table 4 reports estimation results using a random effect Tobit model.[20] Because the Tobit model incorporates the variation in the magnitude of investments (when positive), it improves estimation efficiency provided the model is correctly specified; however, the Tobit model is also less robust to misspecification errors. For comparison purpose, we also report the estimates from random effect linear models that ignore the left-censoring of the data, knowing that such misspecification will bias the estimates toward zero. Indeed, the Tobit estimates are highly significant compared to the linear estimates. Where significant, Tobit estimates for the market size coefficient are of the expected sign. Furthermore, the Tobit estimates for the market composition coefficient are highly significant and negative. Holding downstream market size and initial transmission network size constant, every TWh increase in competitors' presence in the downstream market reduces the latent investment I_{it}^* by 1.04–1.26 miles (when measured as new line length), or by 0.75–0.84 million dollars (when measured as new line cost).

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 5. In each of columns (1)–(4), the first number is the marginal effect on the probability of a positive investment, and the second number is the marginal effect on the investment magnitude. The effect on investment probability is consistent with our results in the binary outcome models: Holding downstream market size and initial transmission network size constant, every

[18] We also estimate both fixed effect and random effect linear probability models, using standard errors adjusted for clustering on utilities. The results are qualitatively and quantitatively similar. In particular, all point estimates remain the same, and all significant estimates remain significant at the same or next higher significance level (i.e., 1% to 5%, and 5% to 10%).

[19] For Probit models, unconditional fixed effect estimates are biased, and conditional fixed effect estimation is unavailable due to the lack of a sufficient statistic that would allow the fixed effects to be conditioned out of the likelihood. For Logit models, conditional fixed effect estimation is available, but utilizes only a fraction of observations (i.e., only 44 of 78 utilities have both 0 and 1 outcomes in their investment decisions). Furthermore, except for the specification in column (3) of Table 3, Hausman tests fail to reject the null hypothesis of no systematic difference between fixed and random effects at 10% for the Logit models.

[20] Similar to the Probit case, in Tobit models unconditional fixed effect estimates are biased and conditional fixed effects estimates are not available.

TWh increase in competitors' generation in the downstream market reduces the probability of a utility making a positive investment by 0.6–0.8%. At the same time, every TWh increase in competitors generation reduces the magnitude of the observed investment I_{it} by 0.49–0.59 miles, or 0.32–0.36 million dollars.

Our estimation results are largely consistent across the empirical specifications we examined. The empirical results are also consistent with our theoretical prediction, developed in Section 3. Where significant, investments in transmission networks depend positively on market size. This may seem obvious—some utilities have more customers or service a larger area than others, and thus tend to have transmission networks that require larger investments for maintenance and upgrades. However, these differences are captured in our regressions by the utility-specific effect u_i and the existing assets variable NETWORK_{it}. The positive dependence of investments on our market size variables MARKET_{it} (i.e., load and total energy) is thus consistent with the non-strategic investment incentive under FRAND open access, namely that higher industry output implies larger investments.

At the same time, we find that upstream investments depend negatively on competitor output (COMPGEN_{it}), after controlling for market size. This result indicates that the strategic investment incentive identified in our theoretical model runs in the opposite direction of the non-strategic incentive: A larger market share by competitors results in fewer, and smaller, investments. Furthermore, the strategic effect of competitor generation on investment is comparable in magnitude to the non-strategic market size effect. This suggest that an increase in total output that stems primarily from increased production by IPPs need not result in an increase in transmission investments by integrated utilities, and could even reduce transmission investments.

6 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) has 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.

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Table 1: Summary statistics (858 observations)

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
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
Competitor generation	(TWh)	9.39	12.48	0.05	159.05

Table 2: Panel estimations using binary outcomes (linear probability specification)

$I(\text{invest} > 0)$	(1)		(2)		(3)		(4)	
	Fixed effects	Random effects	Fixed effects	Random effects	Fixed effects	Random effects	Fixed effects	Random effects
Competitor generation	$-.003$	$-.009^{***}$	$-.005^{***}$	$-.005^{***}$	$-.002$	$-.008^{***}$	$-.005^{***}$	$-.005^{***}$
	(.006)	(.002)	(.002)	(.001)	(.006)	(.002)	(.002)	(.001)
Total energy	$-.003$	$.005^{**}$			$-.003$	$.004^{*}$		
	(.006)	(.002)			(.006)	(.002)		
Load			.003	$.006^{***}$			.002	$.005^{*}$
			(.006)	(.002)			(.007)	(.003)
Total line length	.001	$.003^{***}$	.000	$.003^{*}$				
	(.003)	(.001)	(.003)	(.001)				
Total line cost					.001	$.003^{***}$	.001	$.002^{*}$
					(.001)	(.001)	(.002)	(.001)
$\text{Corr}(u_i, \mathbf{X})$	$-.385$	0	.201	0	$-.360$	0	.237	0
σ_u	.375	.287	.333	.284	.373	.278	.332	.278
σ_e	.351	.351	.351	.351	.351	.351	.351	.351
ρ	.534	.401	.475	.396	.531	.386	.473	.386
Hausman p-value	.352		.609		.123		.194	

Independent variables are lagged by one year. Standard errors reported in parantheses.
* significant at 10%; ** significant at 5%; *** significant at 1%.

Table 3: Panel estimations using binary outcomes (Probit and Logit specifications)

$I(\text{invest} > 0)$	(1)		(2)		(3)		(4)	
	Probit	Logit	Probit	Logit	Probit	Logit	Probit	Logit
Competitor generation	$-.016^{***}$	$-.015^{***}$	$-.008^{**}$	$-.008^{*}$	$-.013^{***}$	$-.013^{***}$	$-.010^{**}$	$-.009^{**}$
	(.005)	(.005)	(.004)	(.004)	(.005)	(.005)	(.005)	(.005)
Total energy	$.010^{***}$	$.010^{***}$			.006	.005		
	(.004)	(.004)			(.004)	(.004)		
Load			$.016^{***}$	$.015^{***}$			$.009^{*}$	$.009^{*}$
			(.005)	(.005)			(.005)	(.005)
Total line length	$.007^{***}$	$.006^{**}$	$.005^{*}$	$.004^{*}$				
	(.002)	(.003)	(.003)	(.003)				
Total line cost					$.009^{***}$	$.008^{***}$	$.007^{***}$	$.007^{***}$
					(.002)	(.002)	(.003)	(.003)
σ_u	1.257	2.168	1.210	2.0763	1.151	1.97	1.148	1.963
ρ	.612	.588	.594	.567	.570	.542	.569	.540

Random effect specification. Independent variables are lagged by one year. Marginal effects are reported, standard errors are in parantheses.
* significant at 10%; ** significant at 5%; *** significant at 1%.

Table 4: Panel estimations using continuous outcomes (linear and Tobit specifications)

New investment	(1)		(2)		(3)		(4)	
	Linear	Tobit	Linear	Tobit	Linear	Tobit	Linear	Tobit
Competitor generation	$-.345^{*}$	-1.260^{***}	$-.182$	-1.044^{***}	$-.033$	$-.753^{**}$	$-.155$	$-.841^{***}$
	(.194)	(.386)	(.153)	(.391)	(.127)	(.321)	(.109)	(.297)
Total energy	$.267^{**}$	$.610^{***}$			$-.184^{**}$	$-.220$		
	(.132)	(.237)			(.092)	(.200)		
Load			$.396^{***}$	$.850^{***}$			$-.160$	$-.181$
			(.146)	(.272)			(.122)	(.251)
Total line length	$.299^{***}$	$.626^{***}$	$.244^{***}$	$.545^{***}$				
	(.087)	(.162)	(.092)	(.169)				
Total line cost					$.467^{***}$	$.851^{***}$	$.461^{***}$	$.834^{***}$
					(.050)	(.112)	(.061)	(.123)
σ_u	14.340	29.778	14.194	29.653	4.950	20.773	4.993	20.808
σ_e	40.472	53.920	40.387	53.773	31.150	40.7940	31.1630	40.846
ρ	.112	.234	.110	.233	.025	.206	.025	.206

Dependent variable for (1)–(2) is new line length (317 left-censored observations). Dependent variable for (3)–(4) is new line cost (323 left-censored observations). Random effect specification. Independent variables are lagged by one year. Standard errors are in parantheses.
* significant at 10%; ** significant at 5%; *** significant at 1%.

Table 5: Marginal effects based on Tobit specifications

Predicted outcome	(1)		(2)		(3)		(4)	
	$Pr(I_{it}>0)$	$E(I_{it})$	$Pr(I_{it}>0)$	$E(I_{it})$	$Pr(I_{it}>0)$	$E(I_{it})$	$Pr(I_{it}>0)$	$E(I_{it})$
Competitor generation	$-.008^{***}$	$-.588^{***}$	$-.007^{***}$	$-.486^{***}$	$-.006^{**}$	$-.324^{**}$	$-.007^{***}$	$-.362^{***}$
	(.002)	(.181)	(.003)	(.182)	(.003)	(.138)	(.003)	(.128)
Total energy	$.004^{***}$	$.285^{**}$			$-.002$	$-.095$		
	(.002)	(.111)			(.002)	(.086)		
Load			$.005^{***}$	$.396^{***}$			$-.002$	$-.078$
			(.002)	(.128)			(.002)	(.108)
Total line length	$.004^{***}$	$.292^{***}$	$.004^{***}$	$.254^{***}$				
	(.001)	(.076)	(.001)	(.079)				
Total line cost					$.007^{***}$	$.367^{***}$	$.007^{***}$	$.359^{***}$
					(.001)	(.051)	(.001)	(.056)

Dependent variable for (1)–(2) is new line length (317 left-censored observations). Dependent variable for (3)–(4) is new line cost (323 left-censored observations). Random effect specification. Independent variables are lagged by one year. Standard errors are in parantheses.
* significant at 10%; ** significant at 5%; *** significant at 1%.

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