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Economies of scale and scope in expansion of the U.S. natural gas pipeline network

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ABSTRACT

I analyze cost, capacity, mileage, and technical data for 254 U.S. natural gas pipeline projects over the period 1997–2012. Although project costs exhibit economies of scale over the capacity margin and economies of scope over the spatial margin, network expansion costs may not exhibit cost economies overall. That is, proportional increases in both transmission capacity and length (in miles) may result in a proportional (or even greater-than-proportional) increase in expansion costs. Moreover, large projects (high-capacity pipelines spanning long distances) likely require installation of compression horsepower, which has direct cost effects. My results suggest such projects exhibit significant diseconomies in cost structure. As a result, pipeline tariffs based on cost-of-service pricing likely present a disincentive for prospective pipeline customers to commit to long-term contracts—which are necessary for the pipeline to acquire regulatory permission to build—particularly for large, long-distance expansion projects. The implication is that cost-of-service pricing may inhibit network expansion, exacerbating congestion issues.

1. Introduction

In the U.S., the prominence of natural gas as a primary energy resource continues to increase dramatically. Domestic recoverable onshore reserve estimates have nearly doubled since the late-1990s (U.S. Energy Information Administration [EIA], 2010a) due to advances in extraction technologies such as hydraulic fracturing and horizontal drilling. EIA predicts production will increase from 22 trillion cubic feet (Tcf) in 2009 to nearly 27.5 Tcf annually by 2035 (EIA, 2011). Concurrently, demand has steadily risen as electrical plant managers shift toward natural gas in response to increased public concern over carbon emissions from coal-fired electricity generation; consumption is expected to grow by 0.6% per year over the next two decades (EIA, 2010b). These projections highlight the importance of a key constraint on the natural gas market—that the links between supply and demand centers are fundamentally limited by the capacity and extent of the pipeline transmission network.

Insufficient transmission capacity results in the emergence of bottlenecks and network congestion, with systematic and measurable effects on transportation costs. Increased transportation costs drive apart natural gas spot prices, resulting in reduced market integration and negative welfare effects (Brown and Yücel, 2008; Marmer et al., 2007; Oliver et al., 2014). Note, for example, the recent divergence in spot prices between the Dominion South Hub in central Pennsylvania, which serves as the primary distribution center for gas produced from the Marcellus shale formation, and Henry Hub in Louisiana, historically regarded as the benchmark spot price for the U.S. natural gas market (EIA, 2014). Remarkably, as of mid-2014, the Dominion price had consistently fallen to as low as 50% of Henry. Because insufficient pipeline transmission capacity exists to carry gas from Marcellus to the Gulf Coast, the glut of production has few options as to where it can be delivered. As a result, spot prices in the Northeast region are depressed, while prices at Henry Hub remain fairly stable. The economic implications are clear: producers in the Marcellus region must accept lower prices than they could if sufficient outgoing pipeline capacity existed, whereas buyers in the Gulf Coast region do not benefit from lower prices at Henry Hub due to cheaper and more abundant supply delivered from the Northeast.

The Dominion-to-Henry example has attracted considerable attention within industry press releases, but is not an isolated occurrence. Delivery constraints are likely to continue to emerge across the country, and expansion of the interstate natural gas pipeline network—both in transmission capacity and mileage—will be crucial to maintaining economic efficiency in the growing domestic natural gas market. Fig. 1 presents a simplified schematic representation of the U.S. interstate pipeline network. Ancillary lines deliver natural gas from supply sources to the high-capacity trunkline, which then transports the gas over long distance, arriving at other ancillary lines that then deliver the gas from the trunkline to demand points. At any given time, an expansion may

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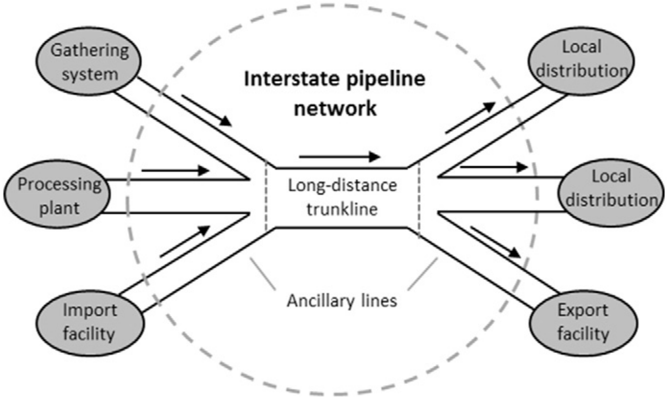

Fig. 1. Simplified schematic diagram of the U.S. interstate pipeline network.

be warranted at any point on the network as transmission demand between different geographical locations grows. These additions must involve installation of sufficient transmission capacity and the required compression horsepower, otherwise congestion and deliverability issues will become increasingly problematic. To keep pace with expected growth in demand for pipeline transmission, the Interstate Natural Gas Association of America [INGAA] (2009) estimates investments in pipeline infrastructure totaling $160–$210 billion are needed over the next two decades to finance expansions averaging 1200–1300 miles per year.

A key concern is whether the cost structure of constructing an expansion project justifies undertaking larger projects, i.e. high-capacity, long distance pipelines, similar to the trunkline in Fig. 1. Most utilities and transportation networks with large infrastructure outlays exhibit economies of scale in the amount of installed transmission or generation capacity. Empirical research has shown that gas pipelines exhibit short-run economies of scale in production, as throughput can be increased at a less-than-proportional increase in pipeline and horsepower capital services (Aivazian et al., 1987). This relates to the engineering aspects of a gas pipeline—increases in diameter and operating pressure yield greater-than-proportional increases in throughput capacity (Yépez, 2008). Economies of scale in production are important, as they generate productivity growth over time.

An under-researched aspect of large transmission infrastructure networks is the prevalence of cost savings generated by economies of scope. Economies of scope exist in a production process when the unit costs of producing two or more different goods or services in combination are lower than would occur under separate production processes (Panzar and Willig, 1981). In the transmission network setting, delivery to different geographic locations on the network is analogous to the production of different goods or services in a traditional economies-of-scope model. Thus, scope economies exist when cost savings emerge as deliverability is expanded spatially to serve a greater number of geographically dispersed customers. Consider a simple but intuitive example of three network nodes—*A*, *B*, and *C*—spatially distributed along a virtually linear geographic arc, such that *B* lies between *A* and *C*. Transmissions from *A* to *B* and from *A* to *C* comprise two distinct services. Clearly, it is less costly to build a single transmission line from *A* to *B* to *C* than to build two separate lines connecting *A* to *B* and *A* to *C*. In this sense, economies of scope surely exist in expanding the pipeline network spatially.

Although economies of scale exist along the capacity margin and economies of scope along the spatial margin, these cost savings may not be powerful enough in combination to result in overall cost economies in network expansion. The importance of this issue relates to the way the Federal Energy Regulatory Commission (FERC) sets pipeline tariffs based on cost-of-service (FERC, 1999; McGrew, 2009). Pipelines earn a specified rate-of-return (ROR) on capital costs—the primary factor in determining rates charged to customers. A pipeline must demonstrate in its FERC application for permission to construct a new infrastructure project that long-term customer contracts (typically 10 years or longer) for all new transmission capacity are in place as evidence of market necessity, and to underwrite the financing of the project (Black and Veatch LLC, 2012; INGAA, 2009).

As capital costs are directly related to the outlays required to construct new pipeline projects, the existence (or non-existence) of cost economies in project construction has clear implications for pipeline customers' commitments to new transmission infrastructure in terms of incentives (or disincentives) related to pricing. If proportional increases in capacity and mileage lead to a greater-than-proportional increase in expansion costs,[1] then by design the pipeline tariffs charged to customers are convex as both the capacity and mileage of a proposed project increase. This implies risk-averse prospective pipeline customers facing uncertain future demand for (or supply of) the gas commodity would be less willing to commit to long-term contracts along high-capacity, long distance pipelines. Insofar as such projects are desirable in terms of improving welfare in the natural gas market via spot price integration, a more robust empirical understanding of the interactions between economies of scale and scope in network expansion is crucial for ensuring that the growth of the pipeline network keeps sufficient pace with growth in transmission demand.

In light of these considerations, the existing literature on this topic is surprisingly sparse. An early paper by Chenery (1952) found empirical evidence that gas pipeline capital costs are concave with respect to capacity, and recent papers by Cremer and Laffont (2002) and Cremer et al. (2003) have made use of this assumption in theoretical analyses. Intuitively, this is perfectly sensible, and relates directly to short-run economies of scale in production. However, as I have argued, this single margin is only one part of the story—it does not alone provide a sufficient measure of cost economies in network expansion. A relatively recent article by Rui et al. (2011) used OLS regression analysis and a log-linearized Cobb-Douglas specification of pipeline construction costs as a function of pipeline length and cross-sectional area. To my knowledge, it is the only other empirical analysis of pipeline construction costs using current data. These authors concluded that because the sum of the estimated cost elasticities with respect to these two characteristics summed to greater than unity, pipeline construction costs exhibit 'increasing returns to scale'.

This conclusion and the empirical results supporting it are suspect for three reasons. First, Rui et al. (2011) do not distinguish between oil and natural gas pipelines, despite different technological parameters governing throughput of each fluid. Cross-sectional area may be a reasonable proxy for the throughput of an oil pipeline, but a gas pipeline's capacity depends on several technological variables, most importantly diameter, operating pressure, and compression horsepower. Each has discernible effects on a gas pipeline's capacity, and must be accounted for individually if proper identification of the variation in project costs with respect to capacity is to be achieved. Second, Rui et al. avoid including compression horsepower altogether, likely introducing omitted variable bias. Installation of compression horsepower has a direct effect on project costs. Third, these authors present little evidence via statistical diagnostics that would help strengthen the validity of their conclusion. I therefore argue that the results of Rui et al. (2011), while meritorious for providing a starting point, are unsatisfactory due to identification and misspecification problems—in particular for natural gas pipelines. A primary goal of this paper is to provide more trustworthy estimates of economies of scale and scope in natural gas pipeline network expansion.

My main contributions to the literature are three-fold. First, the data on pipeline expansion projects were collected directly from hundreds of official FERC filings and are entirely unique to this paper. To my knowledge, no other study of pipeline costs – academic or otherwise – has

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[1] In other words, if pipeline costs as a function of capacity and mileage are homogenous to some degree greater than one.