Elsevier Editorial System(tm) for Energy Policy
Manuscript Draft

Manuscript Number:

Title: Productivity and Efficiency of US Gas Transmission Companies: A European Regulatory Perspective

Article Type: Full Length Article

Section/Category:

Keywords: Gas transmission; regulation; total factor productivity; European energy market reform

Corresponding Author: Mr Thomas Triebs,

Corresponding Author's Institution: Judge Business School

First Author: Tooraj Jamasb

Order of Authors: Tooraj Jamasb; Michael Pollitt; Thomas Triebs

Manuscript Region of Origin:

Abstract: On both sides of the Atlantic the regulation of gas transmission networks has undergone major changes since the early 1990's. Whereas in the US the long-standing regime of rate-of-return regulation was complemented by increasing pipe-to-pipe competition most European countries moved towards incentive regulation and the European Commission has been eager to integrate national markets.

This paper studies the impact of the US regulatory reforms using a Malmquist based productivity analysis for a panel of US companies over the period 1996-2004. Results are presented for changes in productivity, its constituent parts as well as several convergence tests. When taking productivity change as an indicator, US regulation has been rather successful. Though there are differences between various models as well as between technical change and efficiency change overall productivity change is positive during a period where overall demand is flat.

The lessons for European regulators are twofold. First, the US analysis shows what sort of benchmarking of European gas transmission utilities is possible if European data were available on a comparable basis

(which it currently is not). Second, the performance of the competitive US gas pipeline industry provides a benchmark for European productivity performance under incentive regulation.

Productivity and Efficiency of US Gas Transmission Companies:

A European Regulatory Perspective

Tooraj Jamasb[a]

Michael Pollitt[b]

Thomas Triebs[c]

November 2007

[a] Faculty of Economics, University of Cambridge, Sidgwick Avenue, Cambridge CB3 9DE, UK.
[b] Judge Business School, University of Cambridge, Trumpington Street, Cambridge CB2 1AG, UK.
[c] Corresponding Author, Tel: +44 (0) 1223 339700, Fax: +44 (0) 1223 339701 E-mail address: t.triebs@jbs.cam.ac.uk, Judge Business School, University of Cambridge, Trumpington Street, Cambridge CB2 1AG, UK.

Abstract

On both sides of the Atlantic the regulation of gas transmission networks has undergone major changes since the early 1990's. Whereas in the US the long-standing regime of rate-of-return regulation was complemented by increasing pipe-to-pipe competition most European countries moved towards incentive regulation and the European Commission has been eager to integrate national markets.

This paper studies the impact of the US regulatory reforms using a Malmquist based productivity analysis for a panel of US companies over the period 1996-2004. Results are presented for changes in productivity, its constituent parts as well as several convergence tests. When taking productivity change as an indicator, US regulation has been rather successful. Though there are differences between various models as well as between technical change and efficiency change overall productivity change is positive during a period where overall demand is flat.

The lessons for European regulators are twofold. First, the US analysis shows what sort of benchmarking of European gas transmission utilities is possible if European data were available on a comparable basis (which it currently is not). Second, the performance of the competitive US gas pipeline industry provides a benchmark for European productivity performance under incentive regulation.

Keywords: Gas transmission; regulation; total factor productivity; European energy market reform

JEL classification: L51, L95, O57, D24

1. Introduction

This paper measures efficiency and productivity for regulated US inter-state gas transmission pipelines.[1] The objective is twofold. First, we want to show how the performance of US gas transmission pipelines developed and what this might imply for the effectiveness of regulation. Second, this exercise as well as the wider US experience, offers interesting insights for European regulators, and in particular for regulators that implement benchmark-based incentive regulation.

The challenge for any regulator is to increase efficiency and reduce prices, as stated by the European Commission in the second Gas Directive from 2003 ("Acceleration Directive"). Though the process of European gas market liberalization and integration commenced in the mid 1990's the Commission acknowledges in its Acceleration Directive and its recent Sector Inquiry[2] that many obstacles remain.

In this paper we argue that European regulators can benefit from looking across the Atlantic to learn from US experience, including the empirical analysis of US data. Even though the European Commission in its Sector Inquiry acknowledges that the US gas market is much more developed then European gas markets (possibly with the exception of the UK), little effort seems to have been paid to date by European regulators to learn from the US.[3] Also, not much attention has been paid by academia. One exception is a very insightful comparison of the regulatory institutions by Makholm (2007).

---

[1] The authors would like to thank the UK Economic and Social Research Council (ESRC) for supporting this study.

[2] European Commission (2007).

[3] A recent exception is a report we submitted to the Council of European Energy Regulators that benchmarks several European gas transmission operators against US inter-state gas transmission companies [see Jamasb et al. (2007)]. Also, the German network regulator discusses the incentive regulation for gas distribution in Massachusetts and commissioned a report to learn about non-European regulation including the US [see Bundesnetzagentur (2006b)].

Though there are important differences between European and US gas markets and their regulation we believe that looking at the US is a worthwhile exercise for several reasons. First, regulators on both sides of the Atlantic have the same objectives and face similar obstacles. Second, the large US internal market and the public availability of data on regulated entities provide a fertile ground for the empirical analysis that is the focus of this paper.[4] And, most importantly, the mature US industry with its long history of regulation and important regulatory changes over the last two decades offers itself a "benchmark" for the two major challenges facing European regulators: market integration and regulatory reform. Recent regulatory reform in the US moved the gas transportation market from a natural monopoly to a network oligopoly and shifted the regulatory focus from pipelines to markets as argued by O'Neill et al. (1996). This evolution is discussed in more detail below.

At a practical level, the lack of high-quality, standardized data in Europe poses a challenge for the implementation of benchmarking-based incentive regulation. Comparisons with US firms may allow European regulators to produce robust benchmarks. To illustrate this point imagine a single national European regulator had to devise an incentive plan for four companies, which is too few to employ any benchmarking technique. Including data from other European countries might not be a short-run solution as data is not standardized across Europe. When using US data the regulator has to standardize only once and immediately can draw on enough data for a robust empirical analysis.

In our analysis we use efficiency scores and Malmquist productivity indices to shed light on the following questions. How did productivity of US inter-state gas transmission companies develop between 1996 and 2004? Is there convergence in performance? What does this imply for the effectiveness of US regulation? Finally, how can this analysis help European regulators to implement and assess incentive regulation?

[4] The often stunning differences in transparency between the US and Europe are discussed by Makholm (2007). The US approach on transparency is discussed by Olsen (2005).

The productivity of US gas transmission pipelines has already been explored in the literature using firm-level data for earlier periods. Aivazian (1987) measures productivity growth of the US gas transmission industry as well as its constituent parts (for labour productivity) including scale efficiency. The main finding is that the contribution of technical change is at least as large as the contribution of scale economies. There is also a literature on the effect of regulatory change on US transmission companies. Examples are Sickles and Streitwieser (1991), Sickles and Streitwieser (1998), and Granderson (2000). Together these papers show that technical efficiency fell after well-head price deregulation in 1978 due to increasing prices and falling consumption [Sickles and Streitwieser (1991)] and that the regulatory change leading to third-party access in the mid 1980's lead to small cost reductions [Granderson (2000)]. Moreover, up to the early 1990's efficiency scores are diverging [Granderson (2000)]. Given that our sample (1996-2004) starts several years after the latest regulatory push for more access and more competition in 1992 we expect to observe increasing efficiency and possibly convergence.

This paper is organized as follows. Section 2 gives the background and in particular describes the development of the US market and regulation. Section 3 outlines the methodology. Section 4 introduces the variables and Section 5 the data. Section 6 presents the results. Section 7 discusses the results and concludes.

2. Background

Beginning with the deregulation of wellhead prices in 1978 the US natural gas market and its regulation changed dramatically. The market evolved from being vertically integrated and highly regulated to an unbundled, nationally integrated and increasingly lightly regulated market. Though there are many parallels with current efforts in Europe to unbundle, allow third-party access and integrate regional markets one difference is of particular importance here. Whereas most European regulators move to incentive regulation for the unbundled pipeline bits of the value-chain, the US regulator aims at competition through interconnection and secondary capacity markets.

Already in 1987 about one third of city gate markets received services from multiple pipelines according to Kalt and Schuller (1987) as cited by Ellig (1993). Doane et al. (2004) argue that regulatory change led to both an integrated US market for gas, a competitive wholesale market, and competition among, often "virtual", pipelines.[5] Unlike Europe, the United States today has a common market for gas with a single federal regulator for all inter-state commerce (FERC). Tariff setting though still dominated by "original cost-of-service regulation" [O'Neill et al. (1996)] is increasingly complemented by indexing and negotiated rate-setting. Inter-state companies are rate-of-return regulated where FERC sets the maximum and minimum transportation rates. Actual rates are negotiated by the parties involved according to Granderson (2000). Hirschhausen (2006) summarizes US regulation as follows:

> *"Contrary to Europe, where pipeline companies have a high degree of market power, the pipeline business in the US is competitive in many of the regions. Most destination markets are served by several competing pipelines. Thus, pipelines compete for shippers, and rates are negotiated in a competitive environment. On the other hand, there remains a formal cost-of-service regulation of interstate pipelines."*

Thus, whereas European regulators aim at incentive regulation for monopolies FERC aims at complementing traditional rate-of-return regulation with competition through encouraging (or mandating) the development of the necessary market institutions. However, on both sides of the Atlantic regulators have the same objective: increasing

[5] The observation that there is pipe-to-pipe competition obviously runs counter to the natural monopoly argument. Here we do not argue the case for or against natural monopoly as done for instance by Ellig (1993), Aivazian (1987) or Hirschhausen et al. (2007) but simply take the observation from the literature that there is nascent competition.

efficiency[6] and passing on any resulting gains to consumers.[7] In the spirit of Shleifer (1985) both approaches should provide identical incentives for (static) efficiency increases.

As Figure 1 shows regulatory change was accompanied by a large expansion in consumption which might be a first indication of the success of the overall regulatory change in the US. However, our sample period is characterized by fluctuating and slightly downward trending consumption as well as increasing prices.

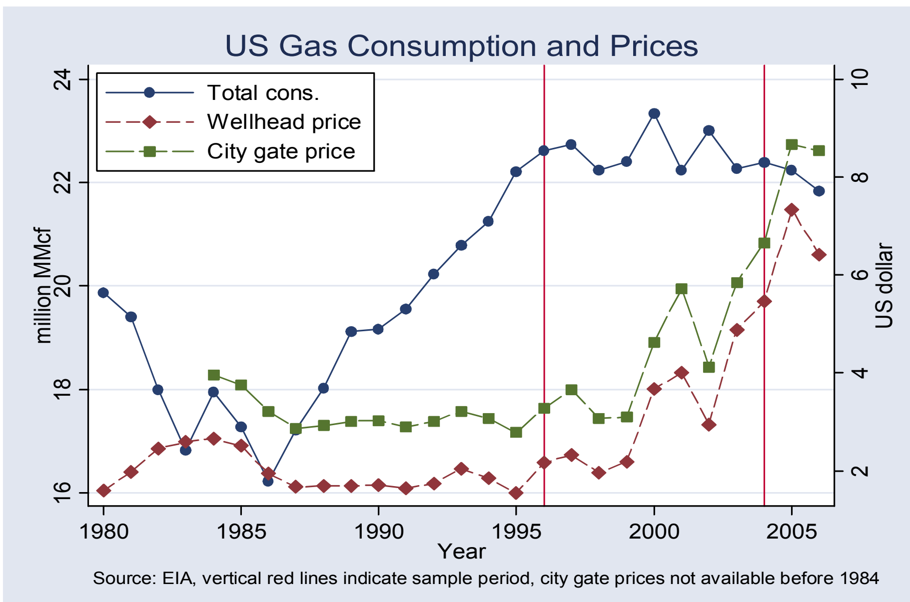

Figure 1: US Gas Consumption and Prices

Besides differences in regulation between the US and the EU there are also differences in industry structure. Table 1 provides an "ad hoc" comparison of the two industries.[8]

[6] Alger and Toman (1990) report on auction experiments commissioned by FERC that investigated the effect of increasing competition and different ways to implement it. An important result from these experiments is that the introduction of small amounts of competition (i.e. adding alternative routes or more competitors on the same route) can lead to a much improved performance of a stylized network.

[7] Even without competitive pressures the regulatory lag might be sufficient to introduce incentives for cost reduction as argued by Sickles and Streitwieser (1998) and Schmidt (2000).

[8] We assume 1bcf/d = 28.33 mcm/d. Because of the different sources the various numbers for Europe are not necessarily for the same sample of pipelines.

We observe the following. The total number of companies is rather similar, measured by the physical characteristics US companies are bigger, and the US network has more interconnection points. As to the last observation one should note that Europe does not fare worse on the relation of interconnection points to total length of pipelines, however.

Table 1: US-Europe Comparison of Industry Structure

	US	Europe (EU-25)
Number of companies	85 inter-state [Energy Information Agency (2002)], 39 inter-state (our sample)	40 national, 38 regional [European Commission (2005)]
Length of pipeline (miles)	212.000 Mean: 2494 St. Dev.: 3775 [Energy Information Agency (2002)]	18.542 Mean: 515 St. Dev.: 608 [Makholm (2007)]
Capacity	133 bcf/d	57.3 bcf/d [European Commission (2007)]
Interconnection points	308[9] Hubs: 14 [Energy Information Agency (2003)]	79 [GTE website][10] Hubs: 13 (however, almost all trading on only 6) [European Commission (2007)]

Another important point is the difference in size as measured by length of pipelines. Though the US mean is several times larger then the European mean the European mean is twice the minimum of our sample as shown in Table 5 below.

[9] Counted as the number of pipeline interconnections at hubs and market centres.
[10] GIE system map at: http://gie.waxinteractive3.com/download/gridmap/GTE_OP_150.pdf

3. Methodology

First, we perform an econometric analysis to test our three candidate outputs or cost drivers. The use of econometrics to determine the relevance of variables prior to employing non-parametric techniques is common practice [see for instance Carrington (2002)]. We discuss the choice of variables in the next section. As we test positive for autocorrelation and heteroskedasticity in our panel we use Generalized Least Squares estimation. We also use log-likelihood tests to compare different models and test the significance of delivery volume as a cost-driver.[11]

Next, the empirical analysis of firm-level efficiency and productivity relies on non-parametric frontier benchmarking techniques. Levels of technical efficiency in a given period are measured using Data Envelopment Analysis or DEA. Changes in total factor productivity (TFPC), technical efficiency (TEC) and technology (TC) between two periods are measured using the Malmquist Productivity Index (MPI) and its decomposition. The MPI is based on DEA.

The advantage of MPI is that unlike other index number approaches it allows to distinguish between technical change and efficiency change. The DEA based implementation was chosen because in a regulated environment it is not clear whether firms are cost minimizing.

DEA is based on a piece-wise linear frontier that envelops the data. Unlike parametric techniques it does not account for measurement error, but does not run the risk of introducing specification error as no functional form is required for the frontier's construction. Once the frontier is constructed efficiency scores for individual observation are based on the distances to the frontier.

---

[11] All our regressions are performed in Stata. To test for autocorrelation and heteroskedasticity we use the *xtserial* and *xttest3* commands respectively. For the GLS estimation we use the *xtgls* command and for the log-likelihood test the *lrtest* command.

One way to account for changes in productivity is to combine single and mixed-period distance functions into an index as pioneered by Caves et al. (1982) and Färe et al. (1989). Next, we present the methodology formally following Grosskopf (1993).

At each time period $t = 1,..,T$ there are $k = 1,\ldots,K$ firms (i.e. decision units) that use a single input $x^{k,t} = (X_k)$ to produce n outputs $y^{k,t} = (Y_{1k},\ldots,Y_{nk})$. For each time period a production technology is constructed using DEA following Farrell (1957) and Charnes et al. (1978). For a given period t the constant returns to scale (CRS) frontier technology is given by:

$$S_{CRS}^{t} = \{(x^{t}, y^{t}) : \sum_{k=1}^{K} z^{k,t}\, y_{n}^{k,t} \geq y_{n'}^{t}, \sum_{k=1}^{K} z^{k,t}\, x^{k,t} \leq x^{t},$$

$$n = 1, \ldots, N, z_{k} \geq 0, k = 1, \ldots, K\}$$

where the upper boundary of this set represents the best practice frontier. Relative to this frontier technology S^t one may define an input distance function for company k:

$$D_{I}^{t}\left(x^{k' t}, y^{k' t}\right) = \min\{\theta : (\theta x^{k',t}, y^{k',t}) \in S^{t}\}$$

Often regulators or regulated firms take issue with the CRS assumption. However, as the Malmquist indices allow for different returns to scale across periods this assumption is not very strong. A more detailed argument is provided by Grosskopf (1993).

Following Färe et al. (1989) and given two time periods (and thus two technologies) four input distance functions can be calculated where two evaluate a period's observations against its respective reference technological and two evaluate its observations against the technology of the other period. The MPI is the geometric mean of these four distance functions

$$M_I(k',t,t+1) = \left[\frac{D_I^t\left(x^{k',t+1}, y^{k',t+1}\right)}{D_I^t\left(x^{k',t}, y^{k',t}\right)} \frac{D_I^{t+1}\left(x^{k',t+1}, y^{k',t+1}\right)}{D_I^{t+1}\left(x^{k',t}, y^{k',t}\right)}\right]^{1/2}$$

As mentioned above an important feature of the Färe et al. (1989) version of the Malmquist index is that it can be decomposed, namely into

$$Technical\ Efficiency\ Change\ (TEC) = \frac{D_I^{t+1}\left(x^{k',t+1}, y^{k',t+1}\right)}{D_I^t\left(x^{k',t}, y^{k',t}\right)}$$

and

$$Technical\ Change = TC = \left[\frac{D_I^t\left(x^{k',t+1}, y^{k',t+1}\right)}{D_I^{t+1}\left(x^{k',t+1}, y^{k',t+1}\right)} \frac{D_I^t\left(x^{k',t}, y^{k',t}\right)}{D_I^{t+1}\left(x^{k',t}, y^{k',t}\right)}\right]^{1/2}$$

and thus

$$M_I(k',t,t+1) = TFPC = TEC * TC$$

Noting that the input distance function is the reciprocal of the Farrell (1957) input-oriented measure of technical efficiency we calculate the distance function for period *t* as

$$\left[D_I^t\left(x^{k',t}, y^{k',t} \middle| CRS\right)\right]^{-1} = \min \theta \ \ s.t.$$

$$\sum_{k=1}^{K} z^{k,t} y_n^{k,t} \geq y_n^t,$$

$$\sum_{k=1}^{K} z^{k,t} x^{k,t} \leq \theta x^t,$$

$$z^{k,t} \geq 0,$$

$$n = 1, \dots N; \; k = 1, \dots, K$$

Further details and the equivalent formulae for the mixed-period distance functions are given in Grosskopf (1993). The Malmquist index and its decomposition are illustrated in Figure 2. The two lines from the origin give the technological frontiers in the two periods. For both periods their respective observations lie somewhat below the frontier.

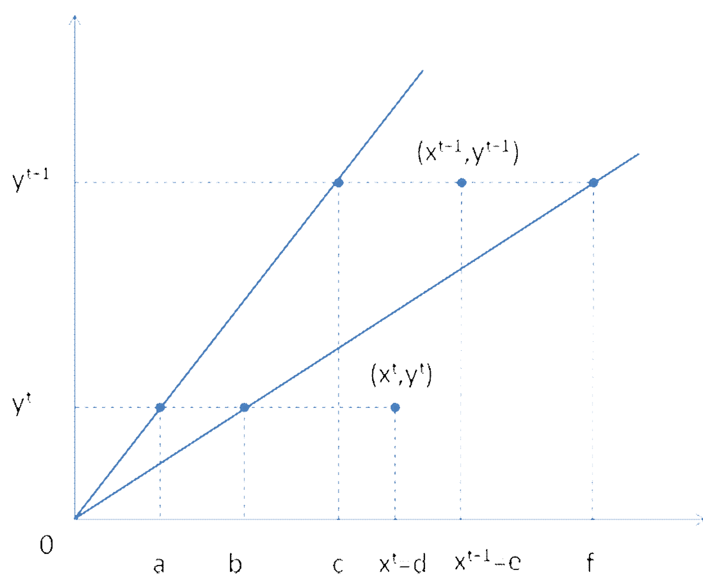

Figure 2: Illustration of a Malmquist Decomposition

Technical efficiency change is given as

$$TEC = \frac{0c}{0e}\frac{0b}{0d}$$

and technical change as

$$TC = \left[\frac{0c}{0f}\frac{0a}{0b}\right]^{1/2}$$

and hence total factor productivity change as

$$TFPC = \frac{0c}{0d}\left(\frac{0b}{0e}\frac{0a}{0f}\right)^{1/2}$$

Note that our Malmquist index is cumulative which means that we use the first year in our sample, 1996, as the base year for all indices. For instance, the index for 2001 is based on the observations for 1996 and 2001. An alternative would be to use an incremental index with changing base years where the two periods are always adjacent. We opted for the cumulative index because for our relatively short time series it provides a smoother path. To rule out the possibility that 1996 is somehow an odd year we also calculated cumulative indices based on 1997 (and dropping 1996). There does not seem to be any systematic difference between the results.

Once we have constructed the technical efficiency scores and the productivity indices we use these to analyze convergence. Following Alam and Sickles (2000) we borrow our convergence concepts from the macroeconomic growth literature which has established two convergence measures, often referred to as β-convergence and σ-convergence. β-convergence is the notion that companies that start from a lower basis grow faster, where β refers the slope coefficient. σ-convergence assumes that changes in the moments of the distribution over time indicate convergence and σ stands for the variance. We perform a total of three convergence tests. First, we graphically relate the level of technical efficiency in the base year (i.e. the DEA score) to our Malmquist based measure of technical efficiency change. Second, following Alam and Sickles (2000) we regress the average year to year growth in the technical efficiency scores (i.e. the DEA score) on the logarithm of the technical efficiency scores in the base year (i.e. the DEA score). For both these β-convergence tests a negative relationship would indicate convergence. Last, we analyze σ-convergence following Färe et al. (2006) and produce the kernel density for the technical efficiency change indices by year. According to Färe et al. (2006) a kernel distribution is essentially a smoothed histogram. Thus, a narrowing of the distribution or a decrease in the variance is an indication of convergence.

4. Variable selection

Though, the technology of gas transportation is not necessarily complex from an engineering perspective variable selection from an economic and from a regulatory perspective is not obvious as different choices produce different results and therefore have different incentive properties. This is also the reason why we do not advocate a "preferred" model but rather outline how different models might be advantageous in different contexts. Our regulatory perspective also determines how we choose our variables. Mainly, our choice is informed by the actual regulatory framework, the literature and our discussions with regulators (see footnote 3). Admittedly, our approach is rather "ad hoc" in the sense that we do not test alternative cost-drivers but rather verify the econometric significance of our variables.

As mentioned above we use an input-output model that for the purpose of our optimization is input oriented and therefore treats the "right-hand side" of our cost model as output and cost as input. To summarize, our inputs are alternatively total cost (Totex) or revenue and our outputs are total length of mains, total compressor station horsepower rating and total yearly delivery volume. The latter is excluded from some models. We now discuss these variables one at a time.

First, we turn to outputs or cost-drivers. Much of the literature uses production functions where the prime output is gas delivered and inputs are capital and labour. Callen (1978), for instance, uses an engineering Cobb-Douglas function where delivery is a function of horsepower and line-pipe capacity and a scale factor. Line-pipe capacity is measured in tons of steel which is a function of length, diameter, and an assumption on wall thickness. Aivazian (1987) and Sickles and Streitwieser (1991) use economic production functions. They use delivery volumes weighted by transport distances as output. Alternatively, Granderson (2000) uses compressor fuel as a proxy for output. Construction cost drivers identified by the International Energy Agency (1994) are: length of pipeline, maximum flow required for a day of peak demand, the trade-off between diameter and compressor power rating, as well as the terrain and right of way. We exclude all exogenous factors as well as right of way. As we have no measure of diameter we only use total horsepower rating and length of mains as outputs representing capacity or capital.[12] The importance of horsepower is that it allows increasing capacity on a given line. Aivazian and Callen (1981) state that:

> *"[…] the line-pipe may take months or years to construct and is clearly the most inflexible input. However, once the line-pipe is in the ground, horsepower capacity may be added fairly continuously to the line to build up capacity."*

Note that the exclusion of other capacity measures might affect comparability. According to the International Energy Agency (1994) the "peak problem" might be solved differently in different countries and at different times as well as by different

[12] As shown by International Energy Agency (1994, Fig. 2) there is a clear relationship between pipeline diameter and compressor power for a given transport volume per year.

firms. Spare capacity, storage and demand response can all address the issue but might be of different importance under different regulatory regimes and for different companies. For instance, as we do not account for storage, its strategic use as addressed by O'Neill (2005) does not infer an advantage. A company that uses storage more cost effectively then others use horsepower and mains will be disadvantaged. Next, we discuss delivery which we alternatively include or exclude.

A reason for the exclusion of delivery is that most costs are fixed. Even most O&M costs (except compressor fuel and compressor maintenance) are fixed as stated by the International Energy Agency (1994, p. 48).[13] Second, as pipelines moved from selling a bundle of transportation services and gas to selling transportation services only, also revenue is less and less driven by delivery.

However, there are reasons for including delivery. Our econometric testing does not unambiguously reject delivery as a cost driver. Revenue is still delivery driven.[14] Increased competition and therefore increasingly diverging business models also imply different approaches to increase capacity and possible delivery in ways that we do not account for (e.g. better systems). Assuming a company uses better management or trading to increase delivery with given capacity, a model excluding delivery would not account for this. Less innovative companies would be rewarded. Generally, it might be possible that the pipeline does not increase delivery even though this would increase welfare because the pipeline is bound by the incentives of the particular benchmarking model.

Including delivery causes a technical problem related our use of Malmquist indices and the fact that delivery shows a rather high year-to-year variability. Coelli et al. (2005, p. 306) and Nghiem and Coelli (2002) explain why variables that fluctuate on a year-to-

[13] The IEA estimates O&M costs for onshore pipelines to be about 2% of investment cost. Maintenance costs for compressor stations run at a relatively high load factor are estimated to be 3-6% of investment costs.

[14] Historically the delivery component of tariffs was greater then the variable cost component to induce pipelines to sell all their capacity. With the development of secondary markets that is no longer necessary and tariffs increasingly reflect cost as argued by Alger and Toman (1990).

year basis potentially cause problems for efficiency measurement results. First, as the frontier is calculated using two years only, DEA based MPI are influenced by stochastic factors.[15] Secondly, a decrease in volume might be interpreted as technical regress. Although our cross-section is much larger then the one used by Nghiem and Coelli (2002) we do observe some technical regress when including delivery volume.

Next, we turn to our input measure. Here unlike most of the literature we use total cost as done by, for instance, Jamasb and Pollitt (2003) and Edvardsen et al. (2006). The latter however uses a Malmquist cost index including input quantities and prices. Also, Rouse and Swales (2006) describe how total expenditure is used as an input into DEA for the pricing of health services in New Zealand. In their case output which is typically measured in number of discharges is cost-weighted to account for the difficulty of different treatments. This illustrates the desirable property of total cost as an input: the proper economic weighting of all inputs.

This choice of input changes the interpretation of our results as compared to standard measures of technical efficiency. Following Maniadakis and Thanassoulis (2004) our measure might be referred to as cost technical efficiency as it implicitly includes allocative efficiency. As we do not have unit prices we cannot distinguish between technical and allocative efficiency as done by Maniadakis and Thanassoulis (2004) who constructed a new Malmquist index that allows for the inclusion of prices.[16] Though one might expect similar input prices across the US (except for labour) the International Energy Agency (1994, Fig. 1 Chapter 3) shows that for construction projects in 1990/91 costs differed for a given pipeline diameter. Sickles and Streitwieser (1991) calculate input prices from revenue and physical quantities. This has the problem that higher margins translate into higher input prices. And in particular with recent increases in rate flexibility it is likely that margins differ across firms.

[15] An alternative would be do estimate MPI using Stochastic Frontier Analysis where the frontier is based on the entire sample and year-to-year fluctuations effect the technical efficiency change component rather then the technical change component as explained by Coelli et al. (2005, p. 306).

[16] Traditionally prices could not be included in Malmquist indices and one would have to resort to parametric techniques to account for prices in productivity measurement as done for instance by Farsi and Filippini (2004).

The main advantage of a single monetary input measure from a regulator's point of view is that correct physical measures are difficult to obtain due to outsourcing, quality differences, or simple non-reporting. Also, as mentioned by Jamasb and Pollitt (2003) our input measure accounts implicitly for all possible trade-offs between the various inputs. Last, consumers (and therefore hopefully the regulator as well) are interested not in technical efficiency as such but the cost of the service. In this light we also use an alternative input measure: total revenue.

When contrasting our results for Totex and revenue models below it is important to keep in mind that the difference between revenue and total cost is obviously profit or excess return on capital. Also revenue is likely to be more volatile. Generally, revenue has two advantages. The first is that total cost, like physical inputs might be difficult to measure and thus revenue can be taken as a proxy. Second, in regulatory practice throughout Europe the rate-of-return is set in lengthy procedures reminiscent of US rate-cases. And like in the US often returns seem to be set rather arbitrarily.[17] To some extend this practice defeats the purpose of incentive regulation by introducing a cost-plus element. Therefore, benchmarking revenue implies that companies are free in setting their returns but at the same time are constraint by best practice. Thus, given the necessary standardization revenue is a very effective and efficient measure from a regulator's perspective. Note that though revenue caps are used by many regulators we are not aware of an example where the revenue is not build bottom-up (like our Totex variable). What we suggest is rather similar to the companies "bidding" a total revenue number without any discussion or scrutiny of its composition.

Last, we do not include any non-discretionary variables in our analysis but suggest considering the following issues. First, as mentioned above the way the systems cope with peaks might differ and not be at the discretion of management. Possible other non-discretionary variables might be the end-use of deliveries (heating vs. industrial) and layout (trunk-line vs. radial grid). Table 2 summarizes the variables and methods used by several studies on productivity and efficiency of the US gas transmission industry.

[17] Joskow (1972) illustrates how rates are set in the US. He observes that (not unlike in Europe) there are complex rules on how the rate base is set but little formal guidance is given for actual rates. Also unlike the other items that make up total cost, cost of capital is unobserved.

Table 2: Summary of the Literature

Author	Data	Inputs	Outputs	Method
Callen (1978)	28 US inter-state gas transmission companies in 1965	horsepower weight of pipeline steel	delivery volume	Econometri c production function
Aivazian (1987)	14 US inter-state gas transmission companies in 1953-1979	horsepower weight of pipeline steel compressor fuel labour	delivery volume multiplied by length of delivery	Econometri c production function
Sickles and Streitwieser (1991)	14 US inter-state pipeline companies in 1977-1985	horsepower weight of pipeline steel compressor fuel labour	delivery volume multiplied by length of delivery	DEA, SFA
Ellig (1993)	50 Texan gas transmission companies, 1989	sales (commercial, industrial, resale) third-party delivery volume total throughput length of pipes gas purchasing cost	O&M expense	Econometri c cost function
Granderson (2000)	20 US inter-state pipeline companies in 1977-1987	horsepower weight of pipeline steel compressor fuel labour	compressor fuel	SFA

Again, in a regulatory context it is important to keep in mind that a certain choice of variables produces a specific set of incentives for companies that are regulated with the help of that particular model.[18] Table 3 summarizes our models. The next section gives the data sources and the variable measurements.

Table 3: Models and Variables

	Model 1	**Model 2**	**Model 3**	**Model 4**
Input	Totex	Revenue	Totex	Revenue
Outputs	Delivery	Delivery		
	Compressor capacity	Compressor capacity	Compressor capacity	Compressor capacity
	Network length	Network length	Network length	Network length

5. Data and Measurement

The data is taken from the Federal Energy Regulatory Commission (FERC) that requires all inter-state transmission companies above a certain size to file a yearly regulatory report containing both financial and operating data (FERC Form 2). As far as possible all data is confined to the transmission function.

Though the data is not explicitly gathered for efficiency and productivity purposes the large numbers of studies (previously referred to) that rely on it testify to its general adequacy. However, several missing values had to be estimated from adjacent periods as MPI do not tolerate any missing values. Also some observations where the data does

[18] Moreover, firms might learn how to game that model as shown by Jamasb et al. (2003).

not appear to be correct were excluded and several obvious errors corrected. The data was corrected for inflation during the sample period. All monetary values are in 2004 US dollars. Revenue was adjusted such that no company had a rate-of-return lower then 6% in any year. This adjustment was made to prevent frontier firms from being those with sub-normal rates of return. Though, essentially six percent is an arbitrary choice, it is chosen to be slightly higher then US interest rates (i.e. the risk free opportunity cost). The adjustment was necessary for five observations. The detailed definitions of the various variables and their measurements are given in Table 4.

Table 4: Variable Description

Variable Name	Description	Measurement
Totex	O&M (less fuel, including labour) + Deprecation + Cost of Capital (written-	2004 $
Revenue	Revenue from transportation of gas of others through transmission pipes.	2004 $
Delivery	Yearly total of gas transmitted for others (excluding losses).	Dth (decatherm)[19]
Mains	Total length of pipes (mains)	Miles
Horsepower (HP)	Total horsepower rating at compressor stations	HP
Age	Accumulated deprecation at mid-year / Annual depreciation	Years
Load factor	Delivery/Capacity (max. past single-day peak*365)	%
Rate of return (ROR)	(Revenue – O&M – Dep.)/Average written-down value	%

[19] 1 therm is equal to 100000 British thermal units (BTU).

Note that we exclude the cost of fuel as it is our understanding that most pipelines withhold fixed percentages of the gas actually delivered as a compensation for compressor fuel usage.[20] Also, we use historic book value as our cost measure which is open to criticism. But Edvardsen et al. (2006) note that historic book value is a reasonable measure as we analyze "efficiency improvement and not static individual scores".

Summary statistics are given in Table 5. It is evident that the size of the companies included varies greatly. In terms of pipeline length the biggest company is about sixty times larger then the smallest company. This reflects the fact that the nature of the companies differs. Whereas some connect several other pipelines in a particular region to benefit from arbitrage, others deliver gas over long distances from the main production regions in Canada and the Gulf of Mexico. For this reason the two largest hub operators were excluded as their delivery to cost ratios are by far the largest.

Table 5: Summary Statistics

Variable	Mean	Std. Dev.	Min.	Max
Obs.: 351, Years: 1996-2004, Firms: 39				
Totex (m$.)	137	112	7.88	540
Revenue (m$.)	263	223	14.2	1100
Delivery (Dth.)	715	589	59	2840
Mains (miles)	4,645	4,117	269	16,666
Horsepower (HP)	395,553	399,938	5,200.00	1,600,000
Age (years)	27	31	4	508
Load factor (%)	0.67	0.19	0.25	1.15
ROR (%)	0.26	0.12	0.04	0.98

[20] This assumption is based on private communication with two companies whose data we include.

Also note that the last three variables Age, Load factor, and ROR (before adjustment) are not included in our analysis but help to describe the sample. For instance the average age is 27 years which is three times our sample length.[21] As discussed below this discrepancy is likely to weaken some of our results.

Figure 3 gives the changes in the yearly sample totals for the variables that are included in the calculation of the MPI. When looking at the output variables we observe that delivery volume fluctuates on a yearly basis whereas total length of pipelines stays virtually constant and total horsepower is continuously increasing.

What is interesting is that while capacity is added total cost and revenue are falling. This might be explained by either pipelines expecting demand to pick up, pipelines taking advantage of arbitrage opportunities, or returns or other costs have been falling.

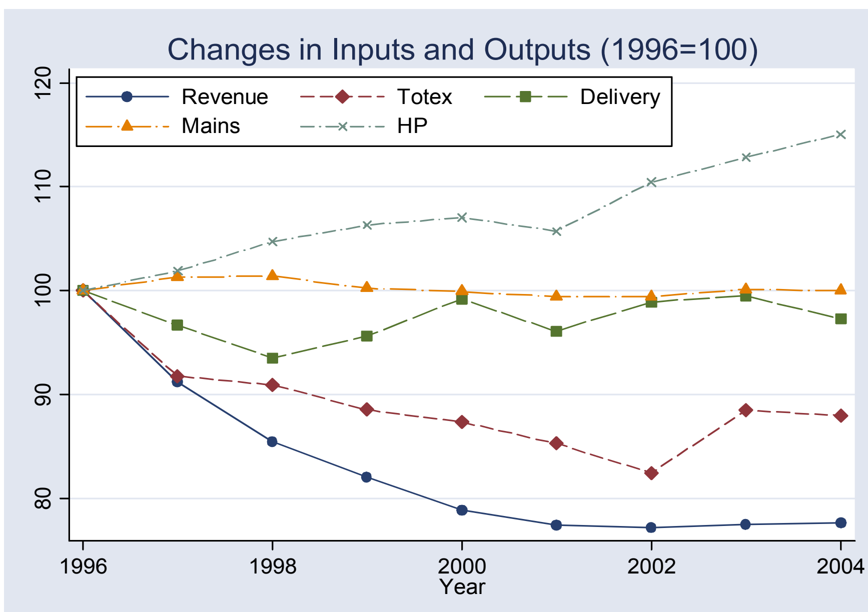

Figure 3: Changes in Inputs and Outputs (1996=100)

[21] The unrealistic measure for maximum age should be due to measurement error or particular accounting practices.

6. Results

Table 6 gives the regression results of the cost driver analysis. As already discussed above there are arguments to believe that total cost does not vary with delivery once we account for capacity. Our results below seem to confirm this. However the coefficient for delivery is larger (and the coefficient for mains smaller) in the revenue model, possible reflecting that tariffs are not entirely cost-reflective in their decomposition.

Table 6: Cost Driver Test Results

	Model 1	**Model 2**
Dependent variable	ln(Totex)	ln(Revenue)
ln(Delivery)	0.267	0.482
	(0.810)	(0.642)
ln(HP)	-0.529**	-0.508*
	(0.201)	(0.248)
ln(Mains)	1.558***	0.842*
	(0.343)	(0.342)
ln(Delivery)^2	0.003	0.000
	(0.020)	(0.016)
ln(HP)^2	0.032***	0.031**
	(0.009)	(0.011)
ln(Mains)^2	-0.086***	-0.042
	(0.022)	(0.022)
Year	-0.016***	-0.025***
	(0.003)	(0.003)
CONSTANT	39.607***	56.250***
	(10.250)	(8.105)
LL	327.72	279.64
AIC	-639.43	-543.29
obs.	351	351
* p<0.05, ** p<0.01, *** p<0.001		

We started with a full Translog but dropped the interaction terms which are not individually significant (possibly due to multi-collinearity). Also, the model reported is the same as the full Translog according to a log-likelihood test. However, even though the two coefficients for Delivery are individually insignificant a log-likelihood test does not suggest that we can drop them. Thus, the empirical evidence on delivery volume as a cost driver is not conclusive. Also, we added a trend whose coefficient confirms that costs (and revenue) are falling over the sample period. Last, it is important to stress that these particular results are likely to be influenced by the actual tariff regime in place (especially for revenue). The results might be different for a different period or a different country.

Now we turn to our main results, the Malmquist productivity indices. Table 7 and Table 8 show the cumulative (and averaged across firms) Malmquist indices (TFPC) and their decomposition into technical efficiency change (TEC) and technical change (TC). Additionally, the yearly technical efficiency scores (TE) which are inputs to the Malmquist indices are reported. The last row in both tables gives the implied average yearly growth rates by taking the index for the last year (2004) and dividing it by the number of years in the sample. Table 7 gives the results for the two Totex models.

Table 7: Average Malmquist Indices and their Decomposition

	Model 1 (Totex, incl. delivery)				**Model 3 (Totex, excl. delivery)**			
Year	TE	TFPC	TEC	TC	TE	TFPC	TEC	TC
1996	0.52	1	1	1	0.45	1	1	1
1997	0.58	1.07	1.13	0.95	0.49	1.14	1.12	1.02
1998	0.61	1.09	1.22	0.91	0.50	1.21	1.18	1.03
1999	0.65	1.12	1.33	0.86	0.50	1.22	1.18	1.05
2000	0.63	1.17	1.30	0.91	0.49	1.25	1.20	1.06
2001	0.61	1.17	1.24	0.95	0.51	1.30	1.26	1.05
2002	0.64	1.25	1.33	0.96	0.52	1.44	1.32	1.11
2003	0.63	1.20	1.32	0.91	0.54	1.42	1.40	1.02
2004	0.64	1.23	1.28	0.96	0.53	1.47	1.41	1.06
growth rate p.a. (%)	-	2.9	3.5	-0.5	-	5.9	5	0.8

First, we observe that the MPI and its components have larger values when delivery is excluded. This is not surprising as length of mains and horsepower (unlike delivery) are virtually non-decreasing. The technical regress for Model 1 might be caused by the fluctuations in delivery as explained above. However, for the static technical efficiency scores the numbers for Model 1 are higher as the additional variable allows more firms to be relatively efficient.

Table 8 gives the same results for the two revenue models. Here TFP growth is stronger because revenue falls more quickly then Totex as shown in Figure 3 above. Also, for almost all models TEC dominates TC. Generally, absolute numbers vary greatly across our four models.

Table 8: Average Malmquist Indices and their Decomposition

	Model 2 (Revenue, incl. delivery)				**Model 4 (Revenue, excl. delivery)**			
Year	TE	TFPC	TEC	TC	TE	TFPC	TEC	TC
1996	0.53	1	1	1	0.44	1	1	1
1997	0.54	1.09	1.04	1.05	0.48	1.18	1.11	1.06
1998	0.59	1.18	1.17	1.01	0.55	1.27	1.34	0.95
1999	0.60	1.20	1.20	1.00	0.54	1.29	1.32	0.98
2000	0.65	1.26	1.32	0.95	0.57	1.33	1.38	0.96
2001	0.60	1.26	1.20	1.05	0.54	1.37	1.32	1.06
2002	0.61	1.31	1.25	1.05	0.55	1.46	1.38	1.07
2003	0.57	1.35	1.16	1.17	0.54	1.52	1.36	1.12
2004	0.56	1.36	1.13	1.21	0.53	1.55	1.35	1.16
growth rate p.a. (%)	-	4.5	1.6	2.6	-	6.9	4.3	2

Looking at the implied *yearly* growth rates Model 1 for instance would produce an average yearly productivity increase of 2.9 percent. These growth rates are higher then in earlier periods as reported by Sickles and Streitwieser (1991) and Granderson (2000). Also, as an example for a US-EU comparison this number might be contrasted with the result of a recent report by the German network regulator [Bundesnetzagentur (2006a)] which found an average yearly TFP growth of 2.19 percent for the entire energy industry for the years 1977-1997 (using a Törnquist index). However, both the different methodologies used by these authors and the different market environment at the time make comparisons difficult. Next, the same numbers are presented graphically. When looking at the results across time they appear to be more similar across models. Figure 4 shows Malmquist indices and their decomposition into technical efficiency change and technical change for the Totex models. Whereas the upper panel includes delivery the lower panel excludes delivery as an output.

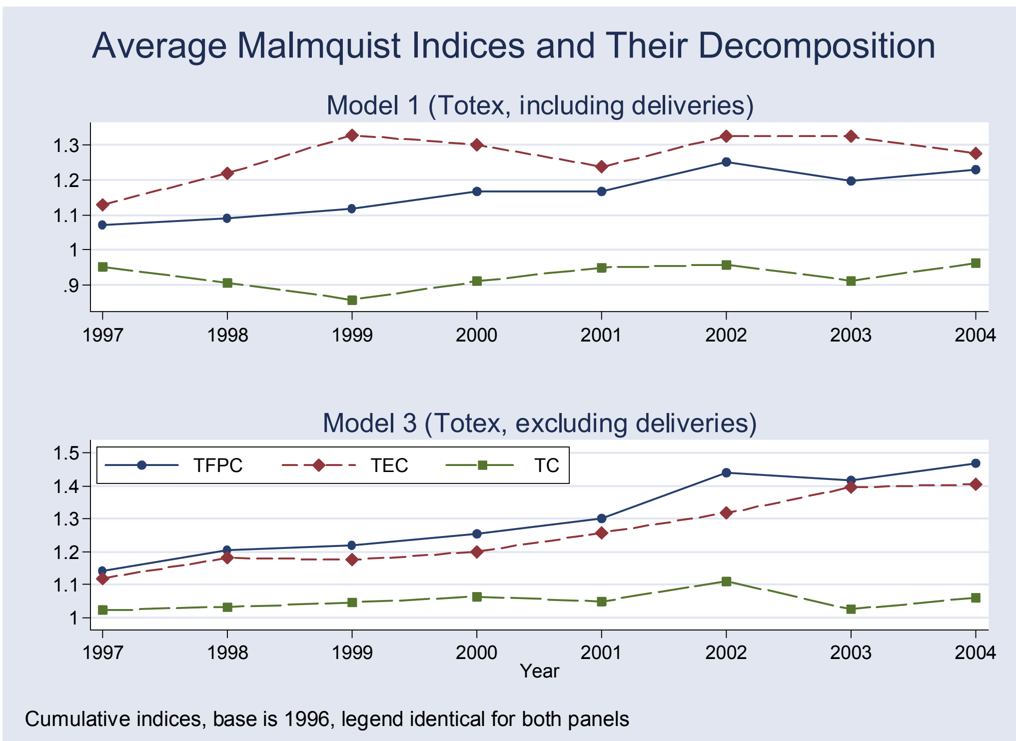

Figure 4: Average Malmquist Indices and their Decomposition

Figure 5 shows a similar pattern for the revenue models. In the second half of the sample period technical efficiency change is falling whereas technical change is much stronger than for the Totex models. While we do not have a good explanation for this we notice that a merger wave in gas distribution and transmission occurred around the year 2000 as shown by Moss (2005). Increasing market power would also explain the discrepancy between the path of the Totex and Revenue based technical efficiency changes.[22]

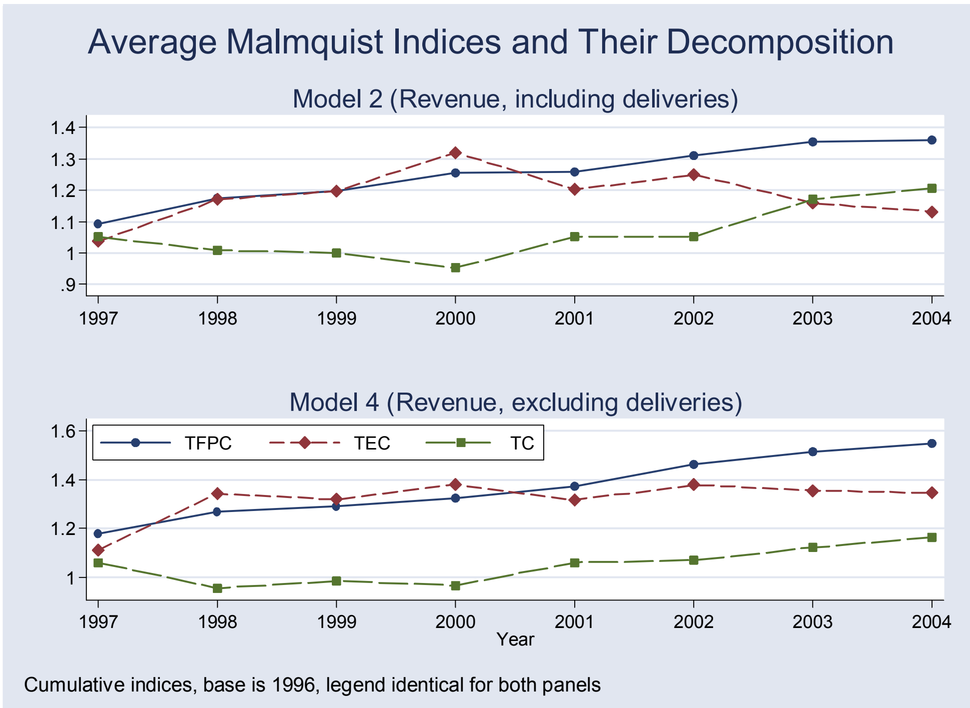

Figure 5: Average Malmquist Indices and Their Decomposition

Table 9 and Table 10 give the Pearson correlation coefficients for the results from the various models. In particular, we are interested in the correlation between the Revenue and Totex models where the results are highlighted along the diagonal in the lower left parts of the two tables.

When focusing on these diagonals two observations can be made. First, the correlation is higher for the level TE scores as compared to the various change measures. Second, the correlations are higher for the models excluding delivery in Table 10. This seems to relate to the presence of volume related charges that effect revenue more than total cost.

[22] In the US like in Europe mergers are decided by the antitrust authorities and not the regulators. In the US the former use a less stringent "no harm" benchmark as discussed by Balto and Mongoven (2001).

Thus, when delivery is excluded the remaining explanatory variables (horsepower and length of mains) have the same relative effect on Totex and Revenue which leads to higher correlations.

Table 9: Pearson Correlation Coefficients, Models including Delivery

		Model 1 (Totex)				Model 2 (Revenue)			
		TE	TFPC	TEC	TC	TE	TFPC	TEC	TC
Model 1	TE	1.000							
	TFPC	-0.134	1.000						
	TEC	-0.166	0.729	1.000					
	TC	0.003	0.403	-0.310	1.00				
Model 2	TE	0.849	-0.130	-0.082	-0.090	1.000			
	TFPC	-0.241	0.589	0.414	0.376	-0.037	1.000		
	TEC	-0.301	0.395	0.428	-0.011	0.049	0.858	1.000	
	TC	0.031	0.293	0.013	0.546	-0.166	0.329	-0.180	1.000

Table 10: Pearson Correlation Coefficients, Models excluding Delivery

		Model 3 (Totex)				Model 4 (Revenue)			
		TE	TFPC	TEC	TC	TE	TFPC	TEC	TC
Model 3	TE	1.000							
	TFPC	-0.215	1.000						
	TEC	-0.267	0.886	1.000					
	TC	0.071	0.262	-0.194	1.000				
Model 4	TE	0.876	-0.167	-0.199	0.071	1.000			
	TFPC	-0.230	0.804	0.682	0.289	-0.091	1.000		
	TEC	-0.278	0.683	0.748	-0.103	-0.084	0.890	1.000	
	TC	0.069	0.238	-0.143	0.848	0.005	0.280	-0.169	1.000

Next, we turn to the results for the convergence tests, looking at β-convergence first. Figure 6 plots the DEA technical efficiency score in the base year against the technical efficiency change component of the MPI (for Model 1). Second, to see what the effect of the sample period length is on convergence, the MPI calculations where repeated for all possible sample lengths moving the base year up by one each time. The different runs are represented by the differently shaped markers and lines. For each value on the x-axis there are several values along the y-axis. These are the values for a given firm across the years. The fitted lines show that the rate of technical efficiency *change* tends to be the higher the lower the *level* of technical efficiency in the base year. Also, this negative relationship weakens the shorter the sample period. Though, we provide no formal test the relationship between the length of the sample period and the strength β-convergence potentially has implications for the length of the regulatory period.

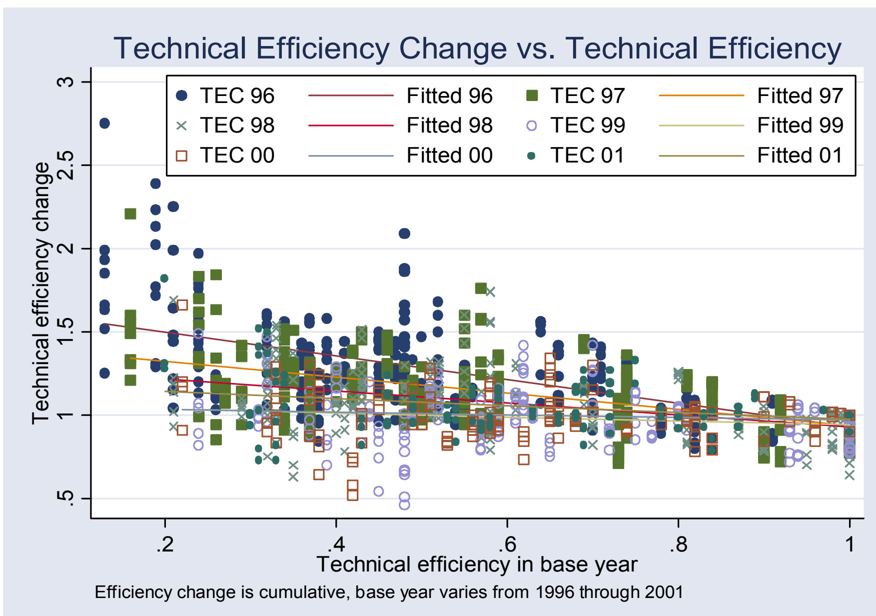

Figure 6: Technical Efficiency Change vs. Technical Efficiency

Next, we present more formal evidence on β-convergence. Following Alam and Sickles (2000) we regress the average year to year growth in the technical efficiency scores on the logarithm of the technical efficiency scores in the base year (i.e. 1996). Table 11 presents the results. The negative coefficient confirms that there is convergence in the efficiency scores. However, the slope coefficient for the revenue model is not significant. Thus, both tests indicate that there is β-convergence.

Table 11: Results of β-Convergence Test

	Model 1	Model 2
Dependent variable	Avg. TE growth for Totex	Avg. TE growth for Revenue
ln(TE96)	-0.019*	-0.019
	(0.009)	(0.011)
CONSTANT	0.003	-0.014
	(0.008)	(0.010)
Prob>F	4.55	3.21
R-squared?	0.09	0.05
No. of obs.	39	39
* p<0.05		

Next, we turn to our results for σ-convergence. Figure 7 gives the kernel distributions of the technical efficiency indices for Model 1 (results for the other models are similar but not shown here). We observe that both the mean and the variance increase over the sample period which implies that there is no σ-convergence. Thus, we do not arrive at a robust conclusion on convergence. Though there seems to be β-convergence we find no evidence of σ-convergence.

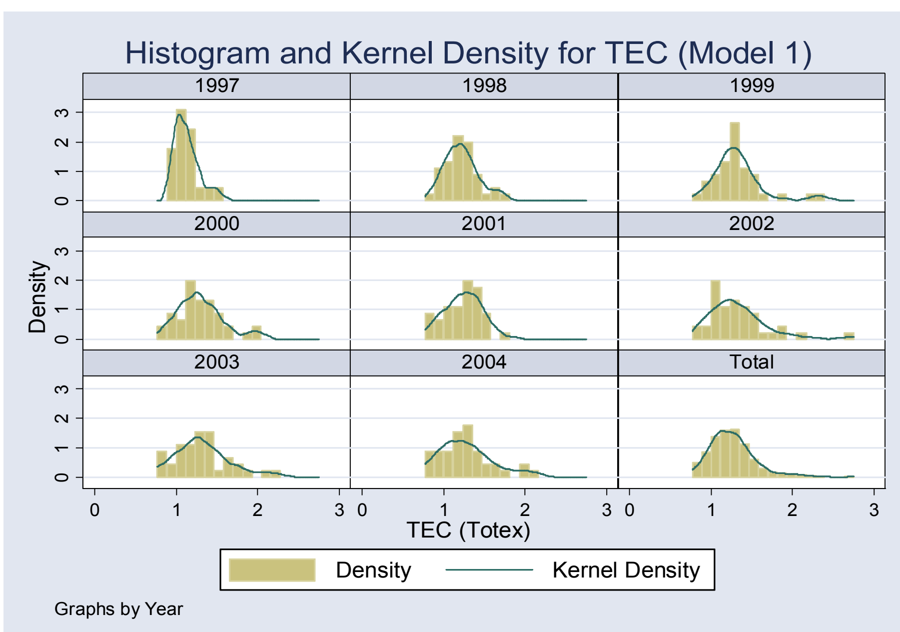

Figure 7: Histogram and Kernel Density for TEC (Model 1)

7. Discussion and Conclusion

7.4. Discussion of Results

Since the liberalization of the well-head price for natural gas in the US and subsequent regulatory change for the pipeline business several studies have measured firm-level efficiency and productivity, and in particular the effect of regulatory change. These studies found that efficiency declined and convergence did not occur in the first decade after well-head price deregulation. In this study, we focus on more recent years and find modest improvements in technical efficiency (and stronger improvements in overall productivity). Moreover, we find some indication of convergence over time.

As to our models, we opted for a single monetary input measure (total cost or revenue) which is not a common approach in the literature but offers several advantages: standard accounting data is sufficient, trade-offs between the various inputs are accounted for, and monetary measures have the advantage that they account for outsourcing and quality differences in inputs. Also, our use of revenue as an alternative input has two desirable features from a regulatory perspective: revenue is the total cost to consumers and aggregate revenue measures are readily available. As we use a monetary input measure but do not include prices (and thus do not distinguish between technical and allocative efficiency) our efficiency measures have incentive properties different from standard technical efficiency measures. Our measure would have the same incentive properties as a standard technical efficiency measure if firms were allocatively efficient and faced the same input prices. The results for Totex and revenue are similar but there are differences. This is not surprising as there are many reasons why revenue might deviate from Totex tough as shown above they track each other in the aggregate for our US sample.

On the output side, we examined models which exclude gas delivery volumes because the literature on costs and our understanding of tariff setting indicate that both are largely driven by capacity rather then volume. Our efforts to confirm this empirically are not conclusive and the productivity results differ depending on whether delivery is included as an output or not.

We report both DEA based technical efficiency scores and Malmquist productivity indices. Though most regulators rely on cross-section based static scores[23] it might be interesting to contrast these with observed productivity changes. We observe that a particular change in the model can lead to different reaction by the two techniques.

As to our results TFP change and TEC seem higher than one would expect for a rate-of-return regulated, natural monopoly industry. For our two Totex models we observe yearly average growth rates of 2.9 and 5.9 percent. For our revenue models it is 4.5 and 6.9 percent respectively. For all models except Model 2 TEC dominates TC. For all models TFPC is upward trending over the entire sample period. For all models except Model 3 TEC is flattening or declining from the year 2000 onwards. Though we have no good explanation for this it might be related to merger activity as discussed above.

Next, we observe some convergence in relative performance. Whereas firms starting at a lower efficiency level grow faster (β-convergence) we do not observe that the dispersion of growth rates (σ-convergence) declines. But even this partial evidence for convergence is telling since in theory rate-of-return regulation unlike competition exerts no pressure to converge. One reason why we only observe limited evidence for convergence might be our relatively short sample length. In order to come to stronger conclusions on converge a sample length equivalent to the investment cycle would be necessary. Also, our results are averages and therefore are likely to gloss over regional differences. As we know that pipeline competition is foremost a regional phenomenon so would be convergence.

---

[23] It is interesting that Ofwat the UK water regulator performs its benchmark on a cross-section even though it has a panel at its disposal [see Weeks and Lay (2006)]. At a presentation of their draft the authors commented that a possible reason for the continued use of a cross-section is that management does not consider itself responsible for the performance of past management teams.

Thus, our results show that regulatory change in the US is accompanied by "cost productivity" and "revenue productivity" improvements. What changed is not so much the actual rate-of-return regulation but the building of competitive markets and increased tariff flexibility (which can be obtained even under an unchanged rate-of-return regulation). Encouraging competition through the creation of the necessary institutions might be more important in the long-run than the prevailing form of tariff regulation. Also, increasing competition might explain why we observe that in a mature industry, with a long history of rate-of-return regulation, technical efficiency change dominates technical change.

7.5. Lessons for Europe

Many European countries recently embarked on a route of regulatory change heading towards incentive regulation. It might be worthwhile for European regulators to see what insights US experience and data offer.

First, our work points towards issues for data collection. Though, FERC data collection is driven by the needs of elaborate rate-cases its overall requirements on transparency and rigour in data collection are an important point of reference. However, FERC recognizes that a move away from rate-of-return regulation shifts the emphasis from quantity to quality for data collection [see O'Neill et al. (1996)]. Our discussion on variable choice above also highlighted that attention should be paid to the proper delineation of the business function that is to be benchmarked. Setting functional boundaries is important for comparability but also determines the incentives the regulator sets.

Broadly speaking, our analysis points towards a short-run and a long-run use of US data. In the short-run European regulators can benchmark individual companies without there being a standardized European data set. In the long-run European regulators could assess the overall performance of the European industry against the US industry. Obviously, the latter would also give an indication of European regulators relative performance vis-à-vis the US regulator.

As to benchmarking individual European companies we remark the following. Though, we do not address comparability in detail we believe (and other regulators have shown[24]) that a sufficient degree of comparability can be obtained with FERC data. We would like to make two general points here. First, once European regulators begin to collaborate on gathering data in a systematic and comparable way there would be enough data to produce robust results from European data only. However, in the meantime comparing European companies to US companies might provide at least some guidance for regulators that often face difficult-to-verify claims from industry. An added advantage of US data is that today a panel is available that allows for more robust conclusions on performance changes simply because single cross-sections are likely to be affected by measurement error. In the long-run, even if sufficient European data was available international benchmarks still have an important role to play. It is possible that US companies embody world best practice. Also, there is no reason to believe that firms under incentive regulation should fare worse then under rate-of-return regulation (complemented by competition or not). To exclude superior management performance from any benchmark would amount to deliberately forfeiting consumer surplus. Therefore, how the US industry performs might set a benchmark for the results from European incentive regulation. Especially as the US strife for market integration and competition might leap-frog European efforts to outperform rate-of-return regulation by adopting benchmark-based incentive regulation.

[24] In particular regulators in New Zealand and Australia have been keen users of US data to benchmark their regulated companies. See, for instance, IPART (1999), Pacific Economics Group (2004), and Carrington (2002).

References

Aivazian, V. A. and J. L. Callen (1981). Capacity Expansion in the U.S. Natural-Gas Pipeline Industry. Productivity Measurement in Regulated Industries. T. G. Cowing and R. E. Stevenson, Academic Press.

Aivazian, V. A., Callen, J.L., Chan, M. W. L., Mountain, D. C. (1987). "Economies of Scale Versus Technological Change in the Natural Gas Transmission Industry." The Review of Economics and Statistics **69**: 55-561.

Alam, I. M. S. and R. C. Sickles (2000). "Time Series Analysis of Deregulatory Dynamics and Technical Efficiency: The Case of the U.S. Airline Industry." International Economic Review **41**(1): 203-218.

Alger, D. and M. Toman (1990). "Market-Based Regulation of Natural Gas Pipelines." Journal of Regulatory Economics **2**(3): 263-280.

Balto, D. and J. Mongoven (2001). "Deregulation and Merger Enforcement in the Natural Gas Industry." Antitrust Law Journal **69**(527-568).

Bundesnetzagentur (2006a). 2. Referenzbericht Anreizregulierung – Generelle sektorale Produktivitätsentwicklung im Rahmen der Anreizregulierung. Bonn, Bundesnetzagentur.

Bundesnetzagentur (2006b). Bericht der Bundesnetzagentur nach 112a EnWG zur Einfuehrung der Anreizregulierung nach 21a EnWG. Bonn, Bundesnetzagentur.

Callen, J. L. (1978). "Production, Efficiency, and Welfare in the Natural Gas Transmission Industry." American Economic Review **68**: 311-323.

Carrington, R., Coelli, T., Groom, E. (2002). "International Benchmarking for Monopoly Price Regulation: The Case of Australian Gas Distribution." Journal of Regulatory Economics: 191-216.

Caves, D. W., L. R. Christensen and W. E. Diewert (1982). "The Economic Theory of

Index Numbers and the Measurement of Input, Output, and Productivity." Econometrica **50**(6): 1393-1414.

Charnes, A., W. W. Cooper and E. Rhodes (1978). "Measuring the efficiency of decision making units." European Journal of Operational Research **2**: 429-444.

Coelli, T. J., D. S. P. Rao, C. J. O'Donnell and G. E. Battese (2005). An Introduction to Efficiency and Productivity Analysis, Springer.

Doane, M. J., R. P. McAffee and M. A. Williams (2004). "Evaluating and Enhancing Competition in the Interstate Natural Gas Transportation Industry." Natural Resources Journal **44**(3): 761-808.

Edvardsen, A., D. Fjeld, F. R. Forsund, W. Hansen, S. A. C. Kittelsen and T. Neurauter (2006). Productivity and Regulatory Reform of Norwegian Electricity Distribution Utilities. Performance Measurement And Regulation Of Network Utilities. T. Coelli and D. Lawrence, Edward Elgar.

Ellig, J., Giberson, M. (1993). "Scale, Scope, and Regulation in the Texas Gas Transmission Industry." Journal of Regulatory Economics **5**: 79-90.

Energy Information Agency (2002). Expansion and Change on the U.S. Natural Gas Pipeline Network. Washington D.C., Energy Information Agency.

Energy Information Agency (2003). Natural Gas Market Centers and Hubs: A 2003 Update. Washington D.C., Energy Information Agency.

European Commission (2005). Technical Annexes to the Report from the Commission on the Implementation of the Gas and Electricity Internal Market. Brussels, European Commission.

European Commission (2007). DG Competition Report on Energy Sector Inquiry. Brussels, European Commission.

Färe, R., S. Grosskopf, B. Lindgren and P. Roos (1989). Productivity developments in Swedish hospitals: A Malmquist output index approach. Discussion Paper No. 89-3, Southern Illinois University.

Färe, R., S. Grosskopf and D. Margaritis (2006). "Productivity growth and convergence in the European Union." Journal of Productivity Analysis **25**: 111-141.

Farrell, M. J. (1957). "The Measurement of Productive Efficiency." Journal of the Royal Statistical Society. Series A (General) **120**(3): 253-281.

Farsi, M. and M. Filippini (2004). "Regulation and Measuring Cost-Efficiency with Panel Data Models: Application to Electricity Distribution Utilities." Review of Industrial Organization **25**(1): 1-19.

Granderson, G. (2000). "Regulation, Open-Access Transportation, and Productive Efficiency." Review of Industrial Organization **16**: 368-385.

Grosskopf, S. (1993). Efficiency and Productivity. The Measurement of Productive Efficiency. H. O. Fried, C. A. K. Lovell and S. S. Schmidt, Oxford University Press.

Hirschhausen, C. v. (2006). Infrastructure Investments and Resource Adequacy in the Restructured US Natural Gas Market – Is Supply Security at Risk? Working Paper, MIT Center for Energy and Environmental Policy Research.

Hirschhausen, C. v., A. Neumann and S. Rüster (2007). Competition in Natural Gas Transportation? Technical and Economic Fundamentals and an Application to Germany. Globalization of Natural Gas Markets Working Papers WP-GG-21b, DIW Berlin.

International Energy Agency (1994). Natural Gas Transportation: Organization and Regulation. Paris, International Energy Agency.

IPART (1999). Benchmarking the Efficiency of Australian Gas Distributors. Sydney, IPART.

Jamasb, T., D. Newbery, M. Pollitt and T. Triebs (2007). International Benchmarking and Regulation of European Gas Transmission Utilities: Final Report, Council of European Energy Regulators.

Jamasb, T., P. Nillesen and M. Pollitt (2003). Strategic Behaviour Under Regulation Benchmarking. Working Paper 0312, Department of Applied Economics, University of Cambridge.

Jamasb, T. and M. Pollitt (2003). "International benchmarking and regulation: an application to European electricity distribution utilities." Energy Policy **31**(15): 1609-1622.

Joskow, P. L. (1972). "The Determination of the Allowed Rate of Return in a Formal Regulatory Hearing." The Bell Journal of Economics and Management Science **3**(2): 632-644.

Kalt, J. P. and F. C. Schuller (1987). Drawing the Line on Natural Gas Regulation. New York, Quorum Books.

Makholm, J. D. (2007). Seeking Competition and Supply Security in Natural Gas: The US Experience and European Challenge. Boston, National Economic Research Associates.

Maniadakis, N. and E. Thanassoulis (2004). "A cost Malmquist productivity index." European Journal of Operational Research **154**: 396-409.

Moss, D. L. (2005). Natural Gas Pipelines: Can Merger Enforcement Preserve the Gains from Restructuring? Working Paper No. 05-08, American Antitrust Institute.

Nghiem, H. S. and T. Coelli (2002). "The Effect of Incentive Reforms Upon Productivity: Evidence from the Vietnamese Rice Industry." Journal of Development Studies **39**(1): 74-93.

O'Neill, R. P. (2005). Natural Gas Pipelines. Network Access, Regulation and Antitrust. D. L. Moss, Routledge**:** 107-120.

O'Neill, R. P., C. S. Whitmore and M. Veloso (1996). The Governance of Energy Displacement Network Oligopolies. Washington, D.C., Office of Economic Policy, Federal Energy Regulatory Commission.

Olsen, W. P. (2005). "Secrecy and Utility Regulation." The Electricity Journal **18**(4): 48-52.

Pacific Economics Group (2004). New Zealand Gas Distribution Cost Performance: Results from International Benchmarking, commissioned by Vector Networks.

Rouse, P. and R. Swales (2006). "Pricing public health care services using DEA: Methodology versus politics." Annals of Operations Research **145**(1): 265-280.

Schmidt, M. R. (2000). Performance-based Ratemaking: Theory and Practice. Vienna, Virginia, Public Utilities Reports, Inc.

Shleifer, A. (1985). "A theory of yardstick competition." Rand Journal of Economics **16**(3): 319-327.

Sickles, R. C. and M. L. Streitwieser (1991). Technical inefficiency and productive decline in the U.S. interstate natural gas industry under the natural gas policy act. Discussion Paper No. 91-6, Center for Economic Studies

Sickles, R. C. and M. L. Streitwieser (1998). "An Analysis of Technology, Productivity, and Regulatory Distortion in the Interstate Natural Gas Transmission Industry: 1977-1985." Journal of Applied Econometrics **13**: 377-395.

Weeks, M. and H. Lay (2006). Efficiency Measurement in the Privatised English and Welsh Water and Sewerage Industry 1992-2004. 13th International Conference on Panel Data, Cambridge, UK.