An empirical study of the economies of scale in AC transmission line construction costs

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***Abstract*—In this paper we use publicly available data filed at the Federal Energy Regulatory Commission to empirically determine the cost of transmission projects completed between the years 1994 and 2000. We examine the economies of scale in the cost of transmission construction.**

***Index Terms*— Transmission costs, economies of scale, nominal capacity, available transmission capability.**

I. INTRODUCTION

Transmission construction costs exhibit economies of scale; that is, the cost of one line of, say, 1000 MW capacity is typically cheaper than the cost of two lines each of 500 MW capacity. Economies of scale in transmission construction costs, together with the complexities of transmission planning and transmission operation, are principal justifications for the continued regulated monopoly status of the electric transmission system as a natural monopoly. The purpose of this paper is to empirically evaluate the cost of transmission projects built in the United States in the last decade using publicly available data filed at the Federal Energy Regulatory Commission (FERC.)

Based on the data filed at FERC, we find that for lines with nominal operating voltages above 200 kV there is little empirical evidence for economies of scale of construction costs when capacity is measured in terms of the nominal capacity of the line. That is, the cost per unit nominal capacity per unit length is roughly constant over the range of nominal capacities in the subset of data that has nominal voltages above 200 kV. For nominal operating voltages below 200 kV, however, there are economies of scale, with cost per unit capacity per unit length declining over the range of capacities in the subset of data that has nominal voltages below 200 kV. These two observations have significant implications for the regulation of the transmission sector of the utility industry. In particular, the costs in the lower voltage parts of the transmission system justify continued natural monopoly status. However, for nominal operating voltages above 200 kV, scale economies are essentially exhausted.

To analyze the cost of transmission construction, we perform a regression analysis of the logarithm of the cost per unit capacity per unit length against various explanatory parameters:

- the year the line went into service,
- the logarithm of the length of the line,
- dummy variables representing the interconnection (Western, ERCOT, Eastern) in which the transmission was built, and
- the capacity of the line.

We used two measures of the capacity of the line. The first measure is the stated nominal capacity of the line. However, because of the need to satisfy security constraints in operation, the nominal added capacity may not correspond closely to the additional capability to transfer power that is due to the addition of the line to the system.

As a second measure of the capacity of the line, we calculated the change in "Available Transmission Capability" (ATC) [4] between the cases of having the line in and out of service. This measure is also somewhat unsatisfactory because the data filed at FERC does not provide information about the purpose of individual transmission lines. To illustrate the issue, note that a line joining busses A and B might have been built in order to increase transfer capability from busses C to D. Without knowing the intended purpose of the line, we cannot evaluate the capability increase for its intended purpose. As a proxy to this, however, for a line joining busses A and B with active power flow in the direction from A to B, we evaluate the change in ATC from A to B between having the line in and out of service.

For various reasons, this proposed proxy may be a biased estimate of the intended change in capability that is due to the line. As an example, consider a new line with large nominal capacity joining busses A and B. Addition of this new line might result in only a relatively small increase in the ATC from A to B if another, smaller, capacity line is actually the determinant of the limit on flow from A to B. The change in the ATC from busses C to D, say, might be relatively larger if the pattern of flows were different for ATC calculated from C to D compared to the ATC calculated from A to B.

Moreover, for each of the three interconnections, we used a single base case study year for all ATC calculations. Potentially, the change in ATC between having the line in and out of service could be different for different study years. Finally, many of the lines may have been built without any specific intention of increasing ATC, but rather may have been built with the intention of enhancing reliability.

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Nevertheless, in the absence of information about the intended purpose of each line, we use the change in ATC as a second measure of transmission capacity added by a line. For all lines and each measure of line capacity, we calculated the cost per unit capacity per unit length and then regressed the logarithm of cost per unit capacity per unit length versus the explanatory parameters.

There are many issues that we could neither measure nor control and therefore could not incorporate into our regression analysis. For example, cost of transmission can depend very strongly on local geographical issues such as the cost of acquiring land and the associated substation upgrades. Variations in these local costs would tend to obscure underlying dependencies on capacity, for example.

An approach to the problem of local variation in costs is to focus on a particular line and evaluate the costs of various alternative construction plans considered during the planning of the line. Presumably all such alternatives would be subject to roughly the same local cost issues. Such analysis was conducted [2] for a small number of lines. However, the FERC data does not include estimates of costs of un-built lines. (Moreover, the cost estimates for un-built lines may not be comparable to the actual costs of a line that is actually built.)

The outline of this paper is as follows. Section II discusses the sources of data, while section III compares the two measures of transmission capacity that we use. Section IV describes the regression analysis. We conclude in section V, discussing some implications for regulation of future transmission investment.

II. SOURCES OF DATA

A. *Cost data*

We used all filings of FERC Form 1 from 1994 to 2000 to obtain information about transmission constructed in the United States in the last decade. While details of reported data apparently vary from utility to utility, these filings typically include the costs of: acquiring land, substation building or expansion, the construction of the line itself, as well as any associated upgrades. We did not try to separately distinguish these costs.

B. *Transmission data*

We used filings of FERC form 715 as obtained from PowerWorld (Power World Corporation, 2003 [5]) to construct our base case transmission systems for ATC calculations. The base case for ERCOT represented a 2002 Summer peak. The base case for the Western Interconnection is a 2004 case. The base case for the Eastern Interconnection is a Summer 2000 case. The filings also included the nominal capacity data for transmission lines. For each line construction reported in the FERC form 1 data, we then found the corresponding line in the power flow data.

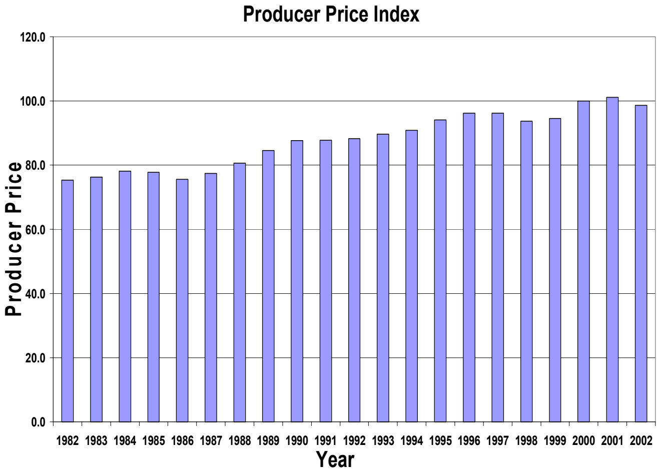

Fig. 1. Plot of Producer Price Factor Vs Year

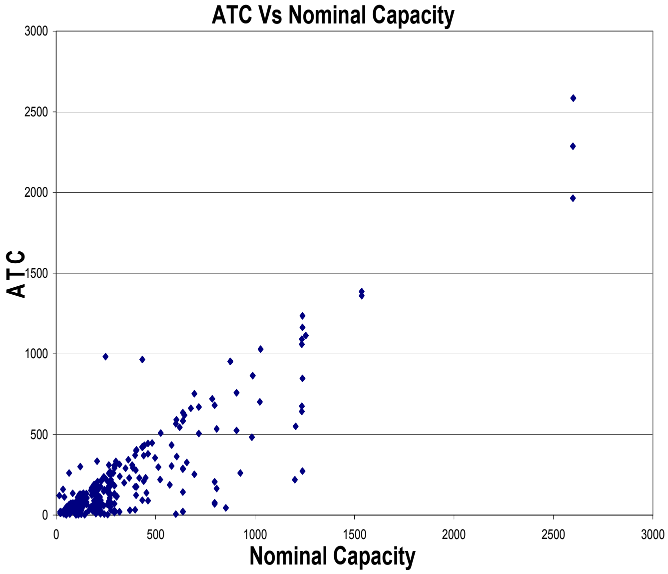

Fig. 2. ATC Vs Nominal Capacity. Note that the value of ATC for every line is different than the nominal capacity of the line.

C. *Producer price index*

The costs filed in FERC Form 1 are in nominal United States dollars for the years concerned. We used the "Producer Price Index" [6] to inflate all the nominal costs to year 2000 dollars. Figure 1 shows the inflation factors for each year. For any year, we take the nominal cost and divide it by the entry in Figure 1 to estimate a cost in year 2000 dollars. We will quote all costs in 2000 dollars.

III. COMPARISON OF CAPACITY MEASURES

We calculated the ATCs with and without each line using PowerWorld. Figure 2 shows the values of the change in ATC versus nominal capacity for each line. As shown in figure 2, the change in ATC is typically smaller than the nominal capacity of the line. However there are some exceptions, including two cases where the change in ATC is more than twice the nominal capacity. As mentioned in the Introduction, in the absence of information about the intended purpose of the project, the change in ATC should be viewed as simply another proxy to the capacity of the line.

IV. REGRESSION ANALYSIS

A. Partition of data by voltage class

Casual observation of the data suggested that lower voltage lines tended to have higher costs per unit capacity per unit length than the higher voltage lines. We therefore partitioned the data into two subsets:

- Lines having nominal voltage below 200 kV and
- Lines having nominal voltage above 200 kV.

We analyzed each subset separately. Table I summarizes the characteristics of each data subset. There were no lines built in ERCOT at voltages above 200 kV during the period covered by the data sample.

B. Nominal capacity

For each line in each subset, we regressed the natural logarithm of the cost per unit nominal capacity per unit length versus:

- The year the line went into service,
- The natural logarithm of the length of the line,
- Dummy variables representing the interconnection (Western, ERCOT, Eastern) in which the transmission was built, and
- The nominal capacity of the line.

We did not include voltage as an explanatory parameter for our basic analysis because of its high correlation with the capacity of the line. We will discuss this issue in section IV.D. However, as noted in section IV.A, we did partition the data into subsets by voltage class, so that the estimates of the coefficients include an implicit dependence on nominal voltage.

Figures 3-4 illustrate the results for the below 200 kV and the above 200 kV data subset, respectively. In each figure, the diamonds show the observed natural logarithm of $/MW(nominal).mile versus the nominal Capacity, the squares show the Predicted Log of $/MW(Nominal).mile Vs Capacity based on the parameter values for the corresponding line, and the solid line shows the least squares regression.

Despite the general trend in costs, there is considerable variation in costs from the regression line. That is, the residuals are large, with standard deviations on the order of 1, corresponding to a typical error in the cost estimate of a factor of approximately three. We consider the distribution of the residuals, first for the below 200 kV dataset and then for the above 200 kV data subset.

Table I

Summary of Test Data

Data Subset Characteristic	Below 200 kV	Above 200 kV
Average of Nominal Capacity (MVA)	196.52	816.88
Number of Lines in Eastern interconnection	142	59
Number of Lines in Western interconnection	81	12
Number of Lines in ERCOT interconnection	17	0
Average Length (Miles)	5.66	13.05

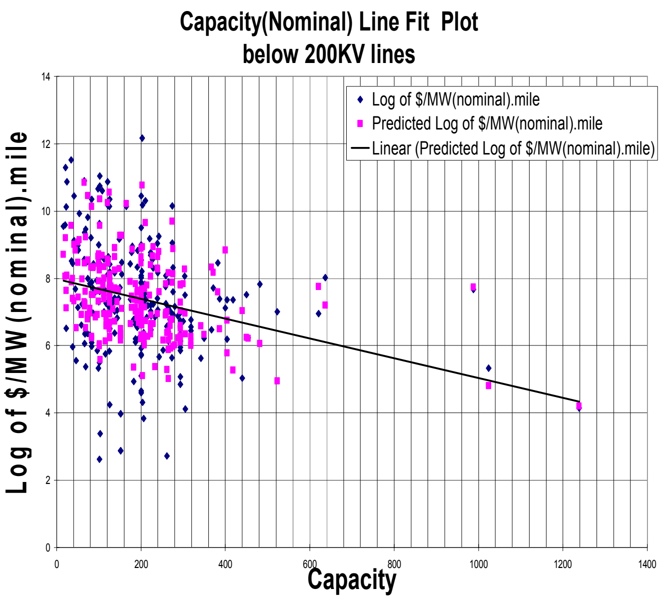

Fig. 3 Line fit plot of Log of$/MW (nominal).mile Vs Capacity (Nominal) for lines with nominal voltage below 200 kV.

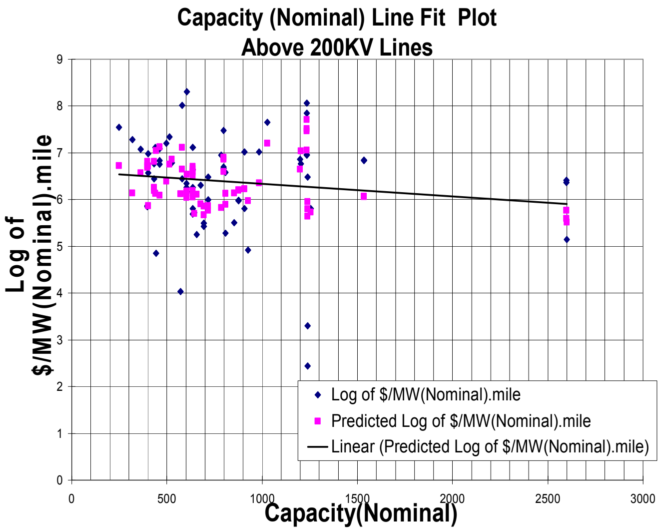

Fig. 4 Line fit plot of Log of $/MW (nominal).mile Vs Capacity (Nominal) for lines with nominal voltage above 200 kV.

Figure 5 shows a normal probability plot of the residuals for the below 200 kV data subset [1]. In this plot, residuals that were normally distributed would appear as a straight line. The residuals in Figure 5 lie approximately on a straight line; however, results from a Shapiro-Wilk normality test and estimates of the skewness and kurtosis of the residuals suggest significant deviation from normality [1]. We will nevertheless assume that the residuals are normally distributed in order to estimate confidence intervals for coefficients. Given that the residuals deviate from normality, these calculated confidence intervals should be used with some caution.

Table II shows the point and interval estimates for the regression analysis for data for lines with nominal voltage below 200 kV, under the assumption of normality of the residuals. Dummy variable 1 is equal to one for lines in ERCOT and zero otherwise. Dummy variable 2 is equal to one for lines in the Western Interconnection and zero otherwise.

Focusing on the dependence of costs on capacity, we obtain a point estimate of –0.00263 and we obtain a 99% confidence interval of [-0.00404, -0.00122] for the coefficient representing the slope of:

- The natural logarithm of the cost per unit nominal capacity per unit length versus
- Capacity of the line.

This confidence interval does not contain zero. That is, with at least 99% confidence we can reject the hypothesis that the slope is zero. In other words, there are economies of scale since costs per unit capacity per unit length decrease with capacity.[1]

For example, consider two lines that were built in the same year, are the same length, and are located in the same interconnection. Suppose that one of the lines has 200 MW nominal capacity, while the other has 400 MW nominal capacity. Then, using the point estimate of the capacity coefficient, we would expect that the 400 MW line would be only approximately 20% more expensive to build than the 200 MW line. That is, the larger capacity line is much cheaper per unit capacity than the smaller capacity line.

Three of the lines in Figure 3 have reported nominal capacities that are greater than 900 MW. This is a rather large nominal capacity for a line with nominal voltage below 200 kV. We were not able to separately verify the data. Consequently, we will consider the regression with these three outliers omitted to see if the results would qualitatively change.

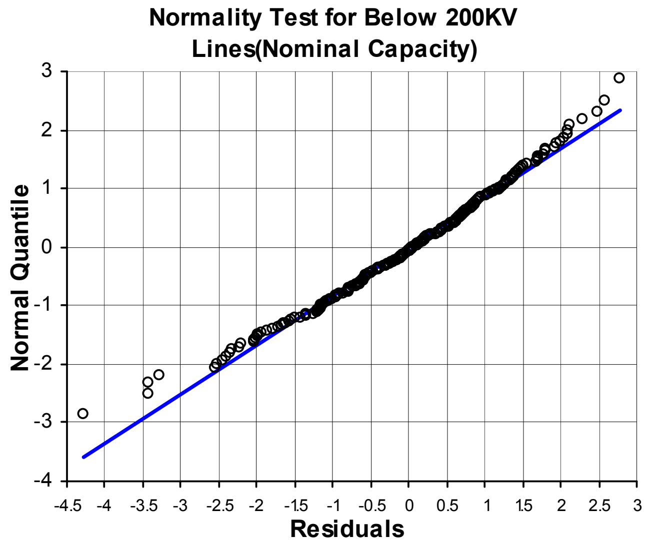

Fig. 5. Normal probability plot of residuals for below 200 kV nominal capacity data.

Table II

Regression Data for below 200 kV Lines (Nominal Capacity)

	Intercept	Capacity	Dummy Variable 1	Dummy Variable 2	Report Year	Log of Length
Coefficients	7.90506	-0.00263	-0.45380	0.26410	-0.13717	-0.59062
Standard Error	0.19915	0.00054	0.31893	0.17828	0.03991	0.04801
t Stat	39.69380	-4.85381	-1.42290	1.48141	-3.43737	-12.30291
P-value	0.00000	0.00000	0.15610	0.13984	0.00070	0.00000
Lower 95%	7.51270	-0.00370	-1.08213	-0.08713	-0.21580	-0.68520
Upper 95%	8.29741	-0.00156	0.17453	0.61534	-0.05855	-0.49604
Lower 99.0%	7.38786	-0.00404	-1.28205	-0.19889	-0.24081	-0.71530
Upper 99.0%	8.42225	-0.00122	0.37445	0.72709	-0.03354	-0.46595

Figure 6 illustrates the results of regression analysis without these three lines and Table III shows the coefficients for the regression. Figure 7 is a normal probability plot of the residuals and comparison with figure 5 confirms that removing the outliers did not significantly affect the normality of the residuals.

Removing the outliers does not weaken the observation that there are economies of scale in transmission construction costs for lines with nominal voltage below 200 kV. Again the 99% confidence interval for the capacity coefficient does not contain zero and we can again reject the hypothesis that the slope is zero. In fact, the logarithm of the cost per unit capacity per unit length decreases even more with capacity when the outliers are omitted. Figure 6 illustrates this point.

To summarize, results from both including and not including the outliers confirm that there are economies of scale for the below 200 kV data subset. However, we emphasize that the residuals deviate from normality so that the estimation of the confidence interval is only approximate.

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[1] We emphasize again that the deviation of the distribution of the residuals from normality weakens this claim somewhat.

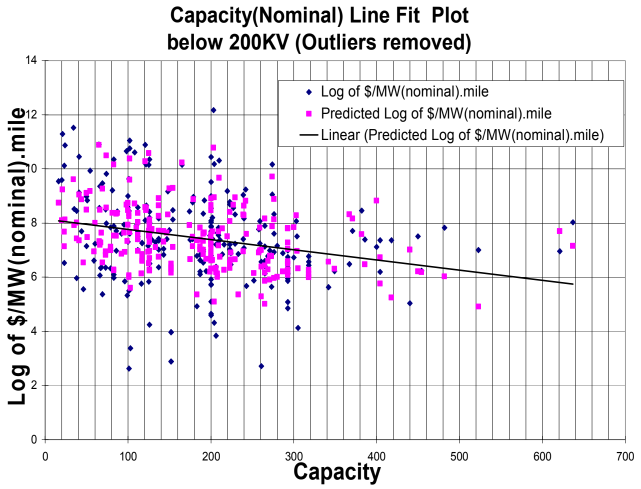

Fig. 6 Line fit plot of Log of $/MW (nominal).mile Vs Capacity (Nominal) for lines with nominal voltage below 200 kVafter removing all outliers.

Table III

Regression Data for below 200 kV (Nominal Capacity) outliers removed

	Intercept	Capacity	Dummy Variable 1	Dummy Variable 2	report year	Log length
Coefficients	7.92348	-0.00276	-0.44608	0.26317	-0.13851	-0.59084
Standard Error	0.23245	0.00078	0.32129	0.18574	0.04052	0.04891
t Stat	34.08652	-3.55138	-1.38839	1.41688	-3.41856	-12.07894
P-value	0.00000	0.00046	0.16635	0.15787	0.00074	0.00000
Lower 95%	7.46548	-0.00430	-1.07911	-0.10279	-0.21835	-0.68721
Upper 95%	8.38148	-0.00123	0.18696	0.62913	-0.05868	-0.49446
Lower 99.0%	7.31974	-0.00478	-1.28056	-0.21925	-0.24375	-0.71788
Upper 99.0%	8.52722	-0.00074	0.38840	0.74559	-0.03328	-0.46379

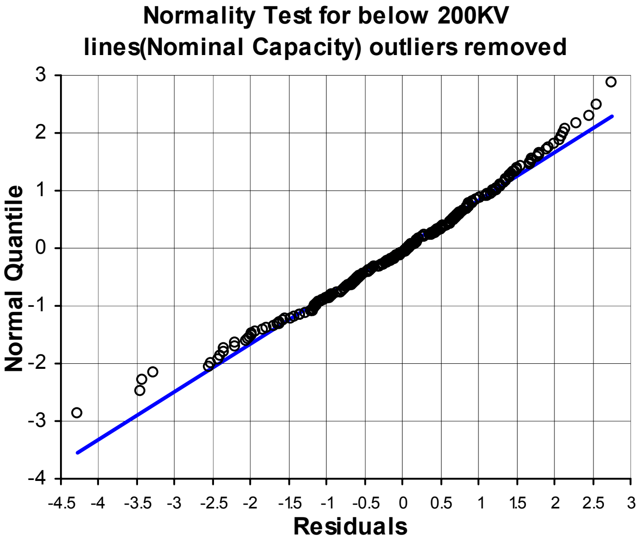

Fig. 7. Normal probability plot of residuals for below 200 kV nominal capacity data with outliers removed.

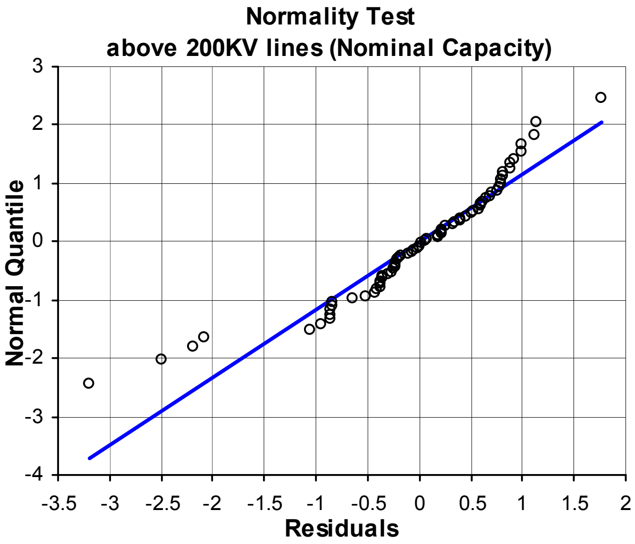

Fig. 8. Normal probability plot of residuals for above 200 kV nominal capacity data.

Table IV

Regression Data for above 200 kV Lines (Nominal Capacity)

	Intercept	Capacity	Dummy Variable 2	Report Year	Log of Length
Coefficients	7.00126	-0.00004	-0.11109	0.03751	-0.28409
Standard Error	0.25568	0.00023	0.29055	0.05640	0.07304
t Stat	27.38312	-0.18029	-0.38235	0.66512	-3.88959
P-value	0.00000	0.85748	0.70343	0.50829	0.00024
Lower 95%	6.49078	-0.00049	-0.69120	-0.07509	-0.42992
Upper 95%	7.51174	0.00041	0.46902	0.15011	-0.13826
Lower 99.0%	6.32310	-0.00064	-0.88176	-0.11208	-0.47782
Upper 99.0%	7.67942	0.00056	0.65957	0.18710	-0.09036

Turning to the data for lines with nominal voltage above 200 kV, figure 8 shows the normal probability plot for the residuals. The residuals again deviate somewhat from normality.

Focusing on the dependence of costs on capacity, we obtain a point estimate of –0.00004 and a 95% confidence interval of [-0.00049, 0.00041] for the capacity coefficient. This confidence interval contains a slope of zero and we cannot reject the hypothesis that the slope is zero. As shown in figure 4, economies of scale for lines with nominal voltages above 200 kV are not very evident; however, the deviation of the residuals from normality weakens this result somewhat.

Using the point estimate of the capacity coefficient, we find that a 400 MW capacity line would cost almost double the cost of a 200 MW capacity line built in the same year in the same interconnection, and having the same length. That is, the cost per unit capacity is very close to constant for the lines with nominal voltages above 200 kV.

We now discuss the dependence of the logarithm of the cost per unit capacity per unit length on the parameters other than capacity. Estimates of the other coefficients are contained in Tables III and IV.[2]

The point estimates for the Dummy variable 1 coefficient are all negative, while the point estimates for the Dummy variable 2 coefficient are all positive. This is consistent with expectations about the relative cost of acquiring corridor space in Texas and the Western Interconnection, respectively, compared to the costs in the Eastern Interconnection. However, the interval estimates for the Dummy variable 1 coefficient and for the Dummy variable 2 coefficient all include zero, so that we cannot reject the hypothesis that the costs are same across all three Interconnections.

The point estimates for the year coefficient are negative for the lines with nominal voltage below 200 kV and the interval estimates for the year coefficient do not include zero. That is, there is a negative correlation of cost (in 2000 dollars) with the year that the line went into service. In contrast, the point estimate for the year of construction coefficient is positive for the lines with nominal voltage above 200 kV but the interval estimates include zero. A positive coefficient is consistent with the expectation that the wide corridors necessary for transmission lines above 200 kV are becoming relatively more expensive over time. Apparently this is not the case, however, for the below 200 kV lines.

The point estimates for the logarithm of length coefficient are always negative and the interval estimates do not include zero. That is, there is a negative correlation of costs per unit length with the logarithm of the line length. This is presumably due to the effect of substation upgrades that are included in the costs and would tend to significantly increase the (overall) cost per unit length of shorter transmission lines. This effect is stronger for the lower voltage lines, which as shown in Table I are on average shorter than the higher voltage lines.

C. Change in Available Transmission Capability

In this section we consider the change in ATC. For each line in each partition, we regressed the natural logarithm of the cost per unit change in ATC per unit length versus:

- The year the line went into service,
- The length of the line,
- Dummy variables representing the interconnection (Western, ERCOT, Eastern) in which the transmission was built, and
- The change in ATC between with and without line.

Figures 9-10 illustrate the regression results for the below 200 kV and above 200 kV data subsets, respectively. In each figure, the diamonds show the logarithm of \$/MW (ATC).mile versus the change in ATC Difference, the squares show Predicted Log of \$/MW (ATC).mile versus ATC Difference, while the solid line shows the least squares regression.

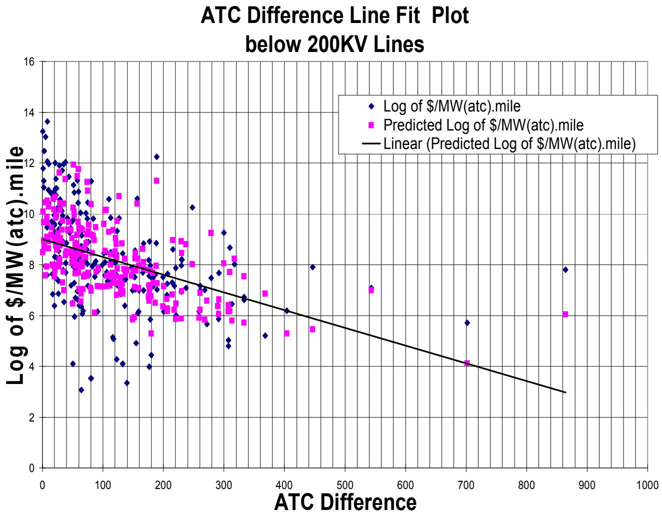

Fig. 9 Line fit plot of Log of \$/MW (nominal).mile Vs ATC Difference for lines with nominal voltage below 200 kV.

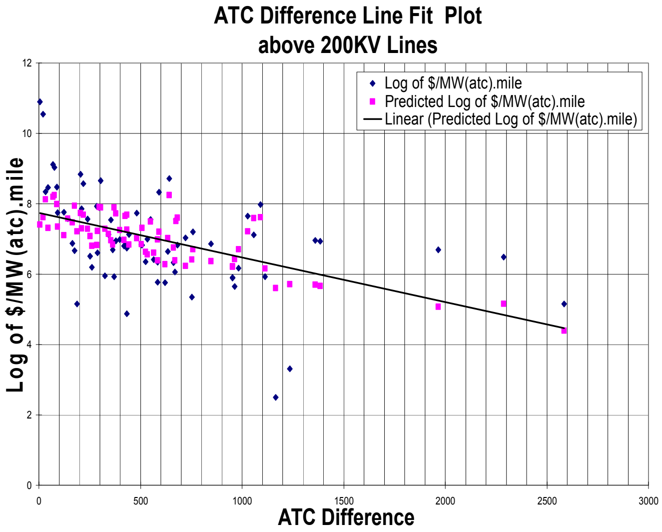

Fig.10 Line fit plot of Log of \$/MW (nominal).mile Vs ATC Difference for lines with nominal voltage above 200 kV.

Figures 11 and 12 show the normal probability plots of the residuals for the below 200 kV and above 200 kV data subsets, respectively. As previously, there is deviation of the distribution of the residuals from normality but we will nevertheless present confidence intervals based on the assumption of normality. Tables V and VI show estimates of the coefficients for the regressions for the below 200 kV and above 200 kV data subsets, respectively.

For the below 200 kV data, a point estimate of –0.00631 and a 99% confidence interval of [-0.00841,-0.00420] is obtained for the coefficient representing the slope of:

- The logarithm of the cost per unit change in ATC per unit length versus
- The change in ATC.

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[2] There is no Dummy variable 1 in Table IV because there were no transmission lines with nominal voltage above 200 kV constructed in ERCOT between 1994 and 2000.

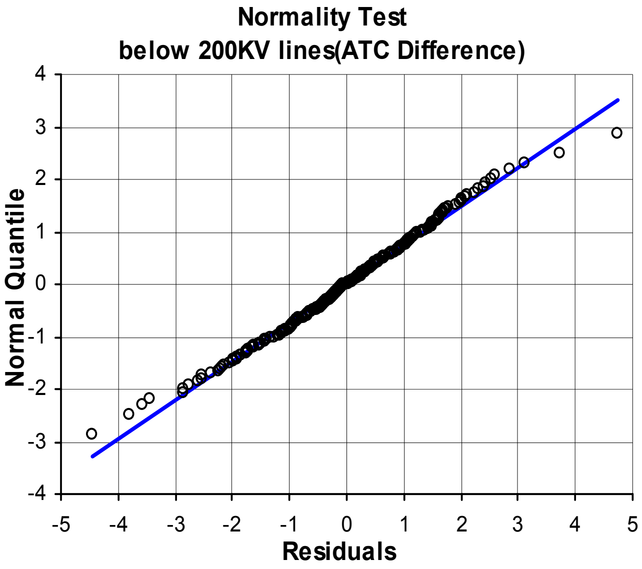

Fig. 11. Normal probability plot of residuals for below 200 kV change in ATC data.

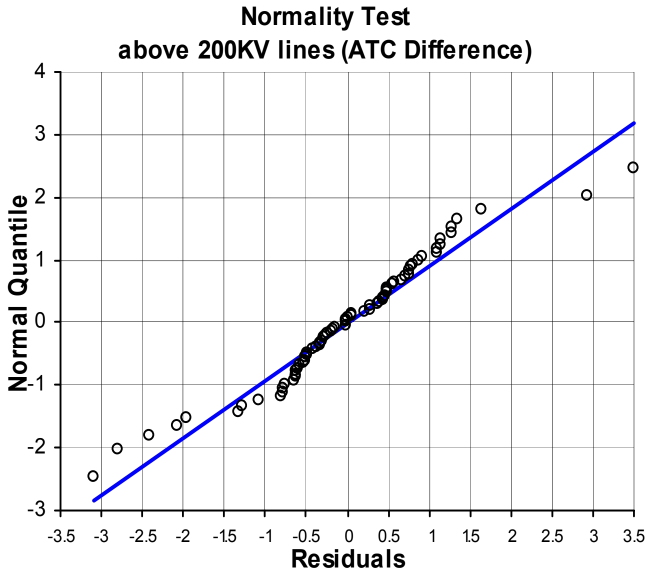

Fig. 12. Normal probability plot of residuals for above 200 kV change in ATC data.

Table V

Regression Data for below 200 kV lines (ATC Difference)

	Intercept	ATC Difference	Dummy Variable 1	Dummy Variable 2	Report year	Log length
Coefficients	9.00625	-0.00631	-0.49305	0.21411	-0.11803	-0.63298
Standard Error	0.21218	0.00081	0.36139	0.20263	0.04511	0.05431
t Stat	42.44563	-7.78691	-1.36429	1.05666	-2.61680	-11.65398
P-value	0.00000	0.00000	0.17379	0.29176	0.00946	0.00000
Lower 95%	8.58821	-0.00790	-1.20507	-0.18511	-0.20690	-0.73999
Upper 95%	9.42429	-0.00471	0.21897	0.61334	-0.02917	-0.52597
Lower 99.0%	8.45519	-0.00841	-1.43163	-0.31214	-0.23518	-0.77404
Upper 99.0%	9.55731	-0.00420	0.44553	0.74036	-0.00089	-0.49192

Table VI

Regression Data for above 200 kV lines (ATC Difference)

	Intercept	ATC Difference	Dummy Variable 2	Report year	Log length
Coefficients	7.92182	-0.00094	-0.20165	-0.06089	-0.30879
Standard Error	0.29312	0.00029	0.36999	0.07330	0.09688
t Stat	27.02593	-3.24033	-0.54502	-0.83065	-3.18727
P-value	0.00000	0.00187	0.58758	0.40916	0.00220
Lower 95%	7.33659	-0.00153	-0.94036	-0.20725	-0.50223
Upper 95%	8.50706	-0.00036	0.53706	0.08547	-0.11536
Lower 99.0%	7.14436	-0.00172	-1.18301	-0.25532	-0.56577
Upper 99.0%	8.69929	-0.00017	0.77971	0.13354	-0.05182

That is, with at least 99% confidence we can reject the hypothesis that the coefficient is zero. In other words, there are again economies of scale since costs per unit capacity per unit length decrease with capacity. As mentioned in the Introduction, the change in ATC may not measure the intended use of the transmission line, so the apparent economies of scale may not be as significant as the regression suggests when measured in terms of the intended purpose of the transmission line.

For the above 200 kV data, a point estimate of –0.00094 and a 99% confidence interval of [-0.00172, -0.0017] is obtained for the slope. This slope is apparently different from zero, but relatively small. That is, while the nominal capacity does not have significant economies of scale for lines above 200 kV, the change in ATC does exhibit some economies of scale. For example, using the point estimate of the coefficient, a line that produces a 400 MW change in ATC would cost about 65% more than a line that produces a 200 MW change in ATC.

Table V shows the estimates of the intercept and slopes and the confidence intervals for all of the parameters for the lines with nominal voltage below 200 kV. Table VI shows the estimates for the lines with nominal voltage above 200 kV. The dependence of the logarithm of the cost per unit change in ATC per unit length on the other parameters is similar to the case for nominal capacity. The main difference are that the dependence on Dummy variable 2 is negative and the dependence on the year is no longer significantly different from zero for the lines with nominal voltage above 200 kV.

D. Dependence on nominal voltage

As mentioned in section IV.B, we did not include voltage as an explanatory parameter, except in that we partitioned the data by voltage class into two subsets. In studies not reported here, we verified that the nominal capacity and voltage of lines are correlated. Consequently, including both nominal capacity and voltage of lines as explanatory variables would yield an ill-conditioned estimate of the dependence on the two parameters. Similar observations apply for change in ATC and voltage.

However, we did perform regression analyses of the natural logarithm of cost per unit capacity per unit length versus:

- The year the line went into service,
- The natural logarithm of the length of the line,
- Dummy variables representing the interconnection (Western, ERCOT, Eastern) in which the transmission was built, and
- The nominal voltage class of the line.

That is, we used the nominal voltage instead of the capacity parameter that was used in the basic analysis. In each case, using the below 200 kV and the above 200 kV subset and considering both nominal capacity and ATC, we found that we could not reject the hypothesis that the coefficient for voltage was zero at a 95% confidence level. That is, there is not strong evidence for economies of scale in construction costs as a function of voltage class.

V. CONCLUSION AND IMPLICATIONS

In this paper we have empirically analyzed the cost of new transmission capacity and upgrades in the United States between 1994 and 2000. There are economies of scale in construction costs for transmission with nominal voltage below 200 kV. However, for transmission with nominal voltage above 200 kV, scale economies are essentially exhausted when capacity is measured in terms of nominal transmission capacity. When measured in terms of the change in ATC with and without the line, there are economies of scale for lines with nominal voltage both below and above 200 kV; however, as discussed in the Introduction, the change in ATC is only a proxy measure of the intended use for many of these lines.

Significant implications for the nature of regulation of future transmission investment stem from the observation that scale economies, in terms of nominal transmission capacity, are essentially exhausted for lines with operating voltage above 200 kV. The observed range of capacities for such lines is from a few hundred MW to several thousand MW.

In comparison, the capacity of typical new large combined-cycle gas turbine generation projects is also in this range, with scale economies also roughly exhausted for capacities above a few hundred MW. That is, construction costs of new generation and of new transmission exhibit similar capacity levels for achieving economies of scale.

Restructuring of the generation sector is, in part, justified on the basis that scale economies in new generation construction are roughly exhausted at generation capacities of several hundred MW, which corresponds to a relatively small fraction of total demand so that competition in the supply of new generation will not result in inefficiently small new generation capacities. The finding that transmission also shows similar characteristics suggests that the regulated monopoly status of transmission with nominal voltages above 200 kV cannot be justified on the basis of economies of scale alone.

As discussed in [3] there are various issues, including the complexity of operation and maintenance of transmission and the difficulty of construction of new lines in restricted corridors, that militate against competitive supply of transmission. Nevertheless, economies of scale of transmission construction can no longer be considered a justification for the regulated monopoly status of future transmission investment, at least for nominal operating voltages above 200 kV.

VI. REFERENCES

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