Constructing a Price Series for Old-growth Redwood by Parametric and Nonparametric Methods: Does Sale Volume Matter?

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Abstract

This paper estimates a price series for old-growth redwood from 1953 to 1977 using both parametric and nonparametric regression. The drawbacks and advantages of each type of technique are discussed. The estimations also show that a very strong perfect-markets assumption that was used in the compensation case surrounding the Redwood National Park was not true.

Keywords: Hedonic, valuation.

Introduction

Old-growth redwood stumpage is a nearly exhausted resource. In 1978, the U.S. Government took about 14 percent of the remaining stock of this resource for use as a park.

The timber companies' suit for compensation subsequent to the taking alleged, among other things, that the volume of a timber sale did not affect its price per board foot. That is, large volume sales should not be sold at a discount relative to small sales. The economic theory that supports this position is known as the Hotelling Valuation Principle, first rigorously tested by Miller & Upton (1985).[2] In this paper the Valuation Principle is again tested, this time with redwood rather than Miller and Upton's oil, and the answer, at least for redwood, is shown to be dependent upon the exact method of regression analysis chosen.

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1 Taking is a legal term of art for a compelled government purchase.

2 Adelman & Watkins (1995) find violations of the valuation principle for a recent set of gas and oil sales. McDonald (1994) explains these in terms of lack of flexibility in well spacing and extraction rates. Hartwick (1991) finds the implications of the valuation principle for an exploring and extracting firm.

The Valuation Principle is tested with three different types of hedonic regressions (regressions of the price of old-growth redwood stumpage sales on the sales characteristics including sale volume, type of buyer and seller, and percent of upper grades). In addition to providing a test of the Valuation Principle, the regressions also provide a size and other quality-adjusted yearly price series for old-growth redwood from 1953 until 1977, which was the date of the second taking of land by the United States for the Redwood National Park.

The three functional forms are linear regression, Box-Cox regression, and Alternating Conditional Expectations (ACE), which is a consistent form of nonparametric regression. Each of these three forms gives a different answer to the test of the Valuation Principle, so the impatient reader may turn to the conclusions to learn whether or not the Valuation Principle can be rejected and what kind of econometrics are needed to find a dependency of price on sale size.

HEDONIC REGRESSIONS AND THE VALUATION PRINCIPLE: THEORY

The fitting of a sale price to its characteristics is a hedonic regression (Adelman & Griliches, 1961) and has been previously applied to forestry by Jackson & McQuillan (1979); Haynes (1980); Brannan *et al.* (1981); and Berck & Bible (1985) though their interests lie elsewhere rather than in redwood or the Hotelling theory.

Brannan *et al.* (1981) focus on methods of producing a price index. Here, their first method, using dummy variables on all of the data, is implemented in three different ways. The focus is not, as in their study, in learning the trend of a standardized price over time. Instead, the focus is upon the effect of sale volume on price.

The hypothesis that sale volume does not affect price is called the Valuation Principle. It applies only to exhaustible resources. Old-growth redwood stumpage (trees standing in the forest available for cutting into logs and milling into lumber) is an exhaustible resource because it takes hundreds to thousands of years to grow trees of this size. The lumber from these trees differs from the lumber from second-growth trees in its density and appearance. The growth in a stand of these trees is almost perfectly offset by decay and death so, for all practical purposes, these old-growth trees are a nongrowing exhaustible resource. Unlike other exhaustible resources, such as minerals, the market for stumpage prices the resource not the product. For instance, copper prices are prices for refined copper. The net price is not observable, so technical progress, change in mining and processing costs, etc., make it possible for the observed, refined price to have many temporal patterns (Slade, 1982, suggests U-shaped) without contradicting Hotelling's view that resources are capital assets with prices that ought to increase at the rate of interest. Stumpage prices are the prices for the resource *in situ*. The buyer of the stumpage pays this price for the resource and then pays to have it felled and milled. Thus, stumpage prices are the net prices described in the Hotelling literature and should obey the Valuation Principle.

The argument for the Hotelling Valuation Principle is an arbitrage argument. A small sale of material will always be made in the year in which it is the most advantageous. An owner deciding to extract in one of two years would choose to sell in the year that has the highest present value of price. Since owners choose to sell in every year, it must be that they expect the present value of price to be the same in every year. Constant present value of price can occur only if prices are going up at the rate of interest, which is Hotelling's rule. Since the present value of price is constant, it does not matter in which year a small sale of material is made.

Now consider the owner of a large parcel. One might reason that, since a large parcel is a large supply in a single year, it would depress the market and sell for less than the price of a small parcel. The counterargument is that a large parcel can be broken up into many small parcels, each one sold in a different year if necessary. Since small parcels are worth the same regardless of the year in which they are sold, it must be that a large parcel is worth no less than a small parcel on a per-unit basis. At least this is true in the Hotelling theory, which is a theory of perfect markets.

Very small sales are likely to incur significant transactions and setups costs, at least on a per-unit basis. Contracting between parties, finding willing parties to a contract, etc., need to be done regardless of the size of the sale. Similarly, men and machines need to be moved to the site of the sale to perform the extracting operations. All of these are in the nature of fixed costs. Insofar as it is not possible to glue many small plots together to make a single large plot, and this is certainly the case in many private timber sales, small sales will sell at a discount. The "market failure," here, is the inability to assemble a sale of minimum efficient size.

The other end of the spectrum represented by very large sales suffers (at least potentially) from a wholly different set of problems. The number of bidders for a very large sale may be few or even one. Particularly, for resources for which specialized immobile capital are necessary for extraction (modern sawmills and private road networks, to name two), the amount of competition may be small. Similarly, $100+ million deals require access to major money markets and may expose the firm to substantial risk of bankruptcy. Although these are stated as reasons why such sales are disadvantageous, the same points could be made in reverse. Large sales allow the construction of modern extraction capital and make it possible to seek financing in the central capital markets at the lowest possible rates. However one argues this, large sales could sell for more or less than small sales with the proper set of market imperfections. What remains, then, is an empirical question. Does the size of the sale affect the price per unit?

Estimates

The real[3] sales price per thousand board feet (MBF) was fitted to the date of sale, the percent of upper grades contained in the sale (one of 40 percent, 50 percent, or 60 percent), the volume of the sale in MBF, dummy variables to indicate the county of sale, and dummy variables to indicate the type of seller or buyer.[4] All of the data, which con-

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[3] The consumer price index was used for the deflation primarily because of its monthly availability.

[4] There is only need for two dummy variables to indicate county and three to indicate buyer-seller type. For instance, the dummy of Del Norte gives the premium of a sale in that county over a sale in the county that has no dummy variable for it, Humbolt.

TABLE 1. VARIABLES IN THE DATA SET.

NAME	SYMBOL	DEFINITION
Price	*P*	Price per MBF divided by (monthly) CPI.
Volume	*VOL*	Number of MBF included in sale.
Volume squared	*VOL2*	Volume squared.
Percent uppers	*PUPP*	Percent of upper grades in sale: measure of sale quality.
Del Norte	*DELNO*	Dummy variable, one if sale in Del Norte county, zero otherwise.
Mendocino	*MENDO*	Dummy for Mendocino county.
Humbolt		True if neither of the above counties
State buyer	*STATE*	Dummy = 1 if bought by state of California.
State seller	*CDF*	Dummy = 1 if sold by state of California.
U. S. seller	*USFS*	Dummy = 1 if sold by U. S. Forest Service.
Private sale		True if none of the above sale types.
Yearly dummy	*D54* etc.	Dummy = 1 if year of sale is 1954.
Month	*MO*	Month number, beginning with Jan., 1953.
Price index	*CPI*	Consumer price index, monthly.

stitute 162 records of actual sales, were developed as part of the legal action surrounding the park taking and are available from the author on request. Table 1 gives the definition of all of the variables in this data set.

The regression methods chosen were ordinary least squares, Box-Cox, and ACE, which is a consistent form of nonparametric regression (Breiman & Freidman, 1985). All of these regression methods are linear in transformations of the variables. Let p be the real price, x_i be the i th dependent variable, and e be an error term. With suitable definition of Φ and ϕ, each method can be represented by

$$\Phi(p) = \sum_{i=1}^{n} \phi_i(x_i) + e. \tag{1}$$

The methods differ in how general these transformation functions can be. And the differences in generality lead to some other changes in formulation amongst the methods, most importantly the ability to make greater use of the monthly information in ACE. The estimators are presented in increasing order of generality.

Ordinary Least Squares

For ordinary least squares, both Φ and ϕ are just multiplication by one for Φ and a parameter, b_i for each ϕ_i. The date of a sale is handled with a dummy variable for each year other than 1953. Volume and volume squared are both entered as variables to allow flexibility in response to volume. With a constant term, this gives n = 34 dependent variables.

The results of the ordinary least-squares regression are given in Table 2. The ordinary least-squares regression certainly fits the data in large part because of the yearly dummy variables. Those variables give the difference in price between the stated year and 1953. They are not statistically significant until the 1960s, so this regression does not even strongly support the hypothesis that price went up during the 1950s. Percent uppers is significant at the 90 percent level, but the effect is quite small — an increase of percent uppers from 40 percent to 50 percent being worth only $5. The other significant variable is *STATE*, showing that the state bought timber worth about $30/MBF more than that generally trading.

Neither volume variable is significant, a point that will be discussed later. A reasonable suspicion as to why this regression does not perform as well as one would like is

TABLE 2. REAL PRICE BY ORDINARY LEAST SQUARES.

Independent Variables	Coefficient	Standard Error	t-statistic
PUPP	0.52	0.28	1.83
VOL	-6.57×10^{-5}	1.88×10^{-4}	−0.35
VOL2	3.11×10^{-10}	9.05×10^{-10}	0.34
MENDO	3.20	4.50	0.71
DELNO	2.54	5.59	0.46
STATE	29.70	15.01	1.98
CDF	2.04	5.29	0.39
USFS	4.64	6.51	0.71
D54	−4.02	8.79	−0.46
D55	7.07	9.31	0.76
D56	8.11	9.31	0.87
D57	12.71	12.92	0.98
D58	7.84	10.90	0.72
D59	12.40	11.13	1.11
D60	13.64	9.88	1.38
D61	12.49	11.69	1.07
D62	7.32	9.74	0.75
D63	14.86	9.81	1.52
D64	20.85	10.73	1.94
D65	25.90	9.77	2.65
D66	32.18	10.69	3.01
D67	15.21	10.84	1.40
D68	36.08	9.88	3.65
D69	36.81	10.35	3.56
D70	51.35	9.68	5.30
D71	27.93	12.48	2.24
D72	29.09	12.72	2.29
D73	91.38	10.87	8.40
D74	108.98	8.97	12.15
D75	76.39	12.67	6.03
D76	83.20	9.16	9.08
D77	136.07	11.71	11.63
CONSTANT	−10.55	15.22	−.70

$R^2 = .83$ Durbin Watson = 2.24

that the functional form forces constant (real) dollar differences for differences in *PUPP*, for instance. Five dollars is a large part of price in 1953, but a vanishing part of price in 1977, so this is unlikely to work well. Since it would be more natural to think of a percent premium, a functional form in logs, or even better, a generalization that includes logs, seems to make sense. The Box-Cox form is the obvious parametric generalization under these circumstances.

Box-Cox Regression

For a Box-Cox regression, $\Phi(p) = (p^{\lambda}-1)/\lambda$ and $\phi(x_i) = b_i(x_i^{\lambda}-1)/\lambda$. The parameters are the b and l; the variables are the same as those for the ordinary least-squares regression. The dummy variables were not transformed. The Box-Cox form includes the case of $\lambda = 1$, which is just ordinary least squares, and (in the limit) $\lambda = 0$, which is a log-log regression. The results of this estimation are in Table 3.

As with ordinary least squares, the fit of the Box-Cox regression is quite acceptable and the evidence of autocorrelation, small. The value of λ is close to (but significantly different from) zero, so the functional form is "closer" to logarithmic than linear (λ is also statistically significantly different from 1). The dummy variables for year are generally significant by the late 1950s, so the real price is certainly rising. The effect going from 40 percent to 50 percent upper grades (all other variables at sample mean) is about a 5 percent change in price (though not statistically significant). The coefficients on volume are both significantly different from zero; their meaning will be discussed below. Finally, the estimated premium for a state sale was \$41 averaged across the years of the sample.

Alternating Conditional Expectations

For ACE, the theoretical restrictions on ϕ and Φ are only that they are measurable mean zero functions. In practice, the transformation functions are those that can be fit with the "super smoother," given the number of data points available. Ordinary least squares and Box-Cox are both (at least theoretically) within the class of functions that ACE can estimate. The functions are not limited to being monotonic, so ϕ could easily be quadratic, cubic, or any other shape. For this reason, it is not necessary to include the square of volume as an explanatory variable. Since ACE can theoretically approximate any measurable function of time, the time variable in this form of the regression was simply the month number with January, 1953, being month zero. The price index was also added to the set of inde-

TABLE 3. REAL PRICE BY BOX-COX.

INDEPENDENT VARIABLES	Coefficient	CONDITIONAL Standard Error	t-statistic
PUPP	0.20	0.23	0.85
VOL	0.22	0.09	2.43
VOL2	-0.04	0.02	-2.18
MENDO	-0.06	0.11	-0.52
DELNO	-0.14	0.15	-0.95
STATE	0.91	0.37	2.44
CDF	-0.07	0.15	-0.49
USFS	0.07	0.17	0.43
D54	-0.30	0.23	-1.32
D55	0.30	0.24	1.24
D56	0.57	0.24	2.39
D57	0.90	0.34	2.69
D58	0.43	0.28	1.53
D59	0.77	0.28	2.70
D60	0.80	0.25	3.13
D61	0.72	0.30	2.38
D62	0.38	0.25	1.50
D63	0.83	0.25	3.29
D64	1.13	0.28	4.09
D65	1.34	0.25	5.32
D66	1.45	0.27	5.28
D67	0.84	0.28	2.98
D68	1.54	0.25	6.07
D69	1.51	0.27	5.65
D70	1.85	0.25	7.40
D71	1.47	0.32	4.57
D72	1.53	0.33	4.67
D73	2.72	0.28	9.71
D74	3.09	0.23	13.28
D75	2.54	0.33	7.79
D76	2.65	0.24	11.24
D77	3.33	0.30	11.04
CONSTANT	1.28	1.11	1.16
λ	0.11		

R^2 = .89

Durbin Watson = 2.32

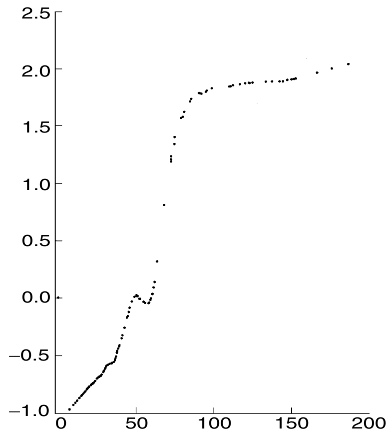

Figure 1. Price and Transformed Price

The actual value of price is on the horizontal axis while the transformed price is on the vertical axis.

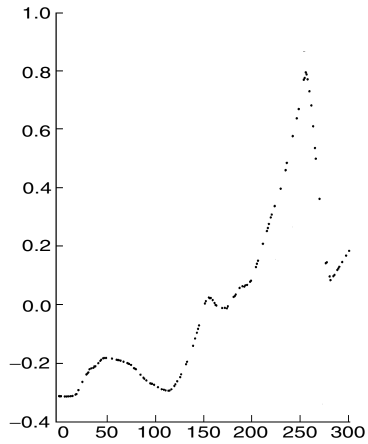

Figure 2. Time and Transformed Time

The actual month is on the horizontal axis while the transformed month is on the vertical axis.

pendent variables so as not to impose homotheticity, the belief that the deflator enters only be dividing nominal price.[5] (Removing the price index changes the plot for time and price and slightly decreases the root mean-square error of prediction but has little other effect.) The ACE also differs from the two previous models in providing maximal correlation not likelihood. The price of this generality is that the results are not parameters or parametric representations of functions, rather they are plots. Thus, the way that one presents ACE results is by presenting the plots of $\phi(x)$ and x, etc. There are no easily publishable statistics to correspond with the familiar t, etc. Tests of hypothesis concerning volume and prediction errors, which are discussed in succeeding sections, depend upon resampling procedures.

The first plot gives the transformation function for price (see Figure 1). The actual value of price is on the horizontal axis while $\Phi(Price)$ is on the vertical axis. The plot is quickly increasing until \$90/MBF and then increasing at a

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[5] The price index is not included in the regressions with yearly dummies because it would be perfectly multicollinear with the yearly dummies. The other methods discussed use dummy variables which impose no practical restriction on "smoothness" of year-to-year price variations. An alternate explanation to the importance of the price index in ACE is that it compensates for the practical limitations of the smoothers.

much slower rate. The second plot (Figure 2) gives month and its transformation. It is increasing until near the end of the period when it drops precipitously. Of course, the cpi changes with time, so one needs to discuss the change in the cpi at the same time as the change in month. Figure 3 gives the cpi and its transformation, a plot which defies easy description.

Taken together, these plots elucidate the relationship of price and time, *ceteris paribus*. If one knew that, in month 144, real price was approximately \$40, one could reason as follows. From the time plot (Figure 2), month 144 has a transformed value of approximately −0.3. A new month, say, month 200, has a transformed value of about 0.1. Thus, in going forward 56 months, the transformed value of y should increase by about 0.4 from the time effect. During that same time interval, the cpi (Figure 3) changes from 94 to 111, so transformed cpi changes hardly at all. Adding the zero change in transformed cpi to the .4 change in transformed month gives a .4 change in transformed price. Now, from Figure 1, the transformed value of price (\$40) was originally about −0.5, so in month 200 it should be −0.1. The price that has a transformed value of −0.1 is about \$50. These sorts of calculations illustrate what the plots mean, but they are not very accurate.

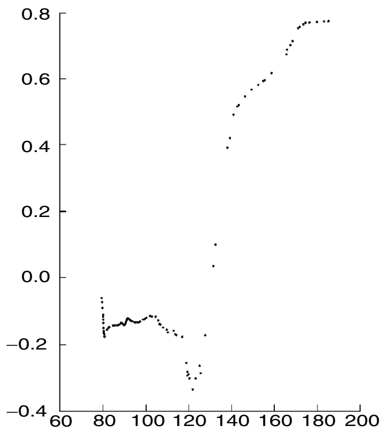

Figure 3. Consumer Price Index and Transformed Consumer Price Index

The actual CPI is on the horizontal axis while the transformed CPI is on the vertical axis.

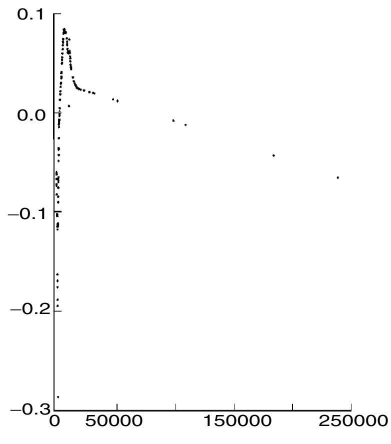

Figure 4. Volume and Transformed Volume

The actual volume is on the horizontal axis while the transformed volume is on the vertical axis.

To make accurate predictions, one uses the ACE prediction procedure, which smoothes price on the transformed independent variables. This method correctly handles the error term (which was done in the above calculation by knowing that the original price was $40).

A change in percent uppers from 40 percent to 50 percent results in a change in transformed price of .05. If price were originally in the 40s, this would result in a $5 increase in price (rough numbers). If price were originally $100, the change would be more like $40–$50. A change in percent uppers from 50 percent to 60 percent results in nearly no price change. The difference in transformed *p* for a state sale is fully 1.4, resulting in a near doubling of a $50 sale price, and an increase in a $100 sale price so large as to be beyond the sample range (the state sales in the sample were all near $70). Figure 4 gives the plot for volume. We defer discussion of the volume plot until the volume section below.

PRICES

The real price prediction of these three models are given in Table 4. The table also includes the price index, which allows ready conversion to nominal prices. The prices given are for a private sale in Humboldt County with the sample-mean volume, 11,234, and the sample-mean percent uppers, 47.03. The price predictions show a tremendous upward trend.

Ordinary least squares and Box-Cox have very similar prediction patterns, exhibiting a good deal of bouncing about from year to year. The ACE, which differs from those methods in smoothing on time rather than using dummy variables, unsurprisingly exhibits a predicted path with much less variation. The differences in methods are particularly pronounced in the last several years of the sample, which were rife with speculation about when, whether, and how much old-growth redwood would be taken for the National Park.

Despite the quite different price series that emerge, all three methods have very similar (cross-validated, jackknifed) root mean-square errors of prediction. The ACE predicts best in this sense with 5.7 percent less error than Box-Cox and 2.1 percent less error than ordinary least

Table 4. Price by Year (Real).

Year	Linear	Ace	Box-Cox	CPI
1953	12.9	21.4	18.6	80.1
1954	8.9	27.9	14.9	80.5
1955	20.0	28.9	23.0	80.2
1956	21.1	25.3	27.9	81.4
1957	25.7	29.1	35.0	84.3
1958	20.8	25.5	25.3	86.6
1959	25.4	29.5	32.0	87.3
1960	26.6	29.2	32.6	88.7
1961	25.4	32.1	30.9	89.6
1962	20.3	36.8	24.4	90.6
1963	27.8	37.3	33.4	91.7
1964	33.8	44.4	40.8	92.9
1965	38.8	47.2	46.8	94.5
1966	45.1	48.5	50.4	97.2
1967	28.2	40.7	33.5	100
1968	49.0	49.9	53.5	104.2
1969	49.8	58.4	52.3	109.8
1970	64.3	61.1	65.2	116.3
1971	40.9	58.7	51.1	121.3
1972	42.0	69.4	53.2	125.3
1973	104.3	101.8	111.1	133.1
1974	121.9	122.8	138.0	147.7
1975	89.3	116.4	99.6	161.2
1976	96.1	116.3	106.4	170.5
1977	149.0	127.8	158.7	181.5

squares. When the criterion is root mean-square percent error, Box-Cox is best with the other two methods over 5 percent (which is also a change of 12 percent from the Box-Cox method) behind.

The analyst in need of a yearly figure for price should be interested in what an "average sale" would sell for and should also be interested in the likely error in that average figure. The prediction errors quoted above are for a single sale. They are composed of two parts, the variation of an individual sale about the regression surface and the variation of the regression surface itself. When one is interested in the average of many sales, all at the same time, only the variation in the regression surface is important. (The central limit theorem assures that, with many sales, the average is nearly the same as the surface itself.) The squared error around the regression surface was 18.78 for ACE, so the excess error was 2.1; in terms of percent error, excess error was 9.2 percent. Thus, the likely root mean-squared error of the prediction of yearly average of price (not that of an individual sale) is 9.2 percent using ACE. For Box-Cox, excess error is 4.35 or 10 percent and, for ordinary least squares, the figures are 5.1 and 12.2 percent. Thus, if one is interested in an "accurate" price series for yearly average price, ACE or Box-Cox would seem to be the method of choice. Given the practical limitations of the super smoother used by ACE, which is to say that the authors belief that the yearly prices actually bounce around a good bit, the Box-Cox approximation to prices would seem preferred.

VOLUME

Figure 5 presents the estimated price per board foot as a function of the number of board foot sold for a private sale in Humboldt with 47 percent uppers in 1976. The plots for both of the flexible methods of estimation show a marked change in price with volume. The burdening of very small sales, which should be expected, is present. In the ACE plot, the very large sales are worth only a little less than the optimal-sized sale. In the Box-Cox plot, the very large sales are more considerably burdened. Ordinary least squares shows the smallest sales as worth the most.

Examining the hypothesis that the curves slope up at the beginning gives a little clearer picture. For ACE, a bootstrap was used to test this hypothesis. In all but one of 200

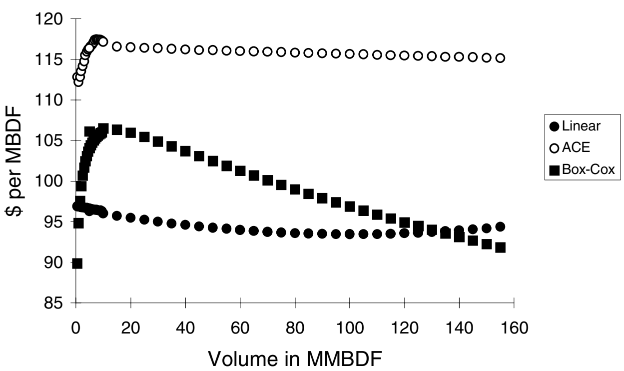

FIGURE 5. PRICE AND VOLUME (REAL)

bootstrap replicates, the price-volume curve was increasing at low volumes. For Box-Cox, a Wald test was used to see if the slope was different from zero and a $\chi^2_{(1)}$ statistic of 7.6 rejects the slope was zero. In the case of ordinary least squares, the hypothesis cannot be rejected (t = .346). Since it was already shown that ordinary least squares is a very improbable restriction on Box-Cox to begin with, the clear conclusion is that the price per board foot increases with volume.

At the high end of the curve, there is some evidence of a price decrease. Eighty percent of the bootstrap replicates show a decrease in price at the high end. A very large sale is worth about 2 percent less than an average sale. The downward slope of the Box-Cox is also not significant statistically, but a large sale is worth 14 percent less than an average sale. These results do not contradict Miller & Upton's (1985) study of petroleum because those authors observe costs. Nothing is said about whether or not very small fields (which they actually exclude from their study) have higher or lower costs than large ones. The argument made here is simply that average extraction costs fall with volume initially. Thus (in any given year), observed bid price is just product price less costs, and it, too, falls initially as volume increases. A conclusion about comparing very large sales to the sort of medium-sized sales in the sample seems premature; there is some evidence that they are worth less.

Conclusion

Both simple and very complicated regression methods have similar success in prediction, but the simple method, ordinary least squares, was not capable of finding the true effects of volume, a variable of great importance.

Since volume is clearly an important determinant of sale price, at least for small sales, one must either abandon the perfect capital markets argument implicit in Hotelling's model or the assumption of there being no scale economies in timber harvesting activities. Whichever assumption one abandons (and I would abandon the no efficiencies of scale argument), the conclusion that natural resource sales of different sizes are comparable is not justified.

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