The Price-Elasticity of Stumpage Sales from Federal Forests

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Abstract

This paper explores the influence of the behavior of the Forest Service and Bureau of Land Management on effective public policy toward the national forests. It shows that fluctuations in stumpage sales from such forests have been large. Furthermore, those fluctuations could well have a significant impact on the price elasticity of harvest even with large stocks of uncut volume under contract. System analysis of harvest and sale patterns in nine regions during the period 1951-1992 shows that stumpage sales displayed little correlation with prices during the period; the positive price elasticity of harvest seems to have been induced largely by the behavior of logging firms. However, it finds a positive link between National Forest budgets and annual sales. If budget appropriations had been negatively correlated with stumpage prices, the price elasticity of harvest from federal forests could have been severely damped.

Key Words: stumpage, harvest, sales, National Forests, budget, price elasticity

JEL Classification Nos.: Q23, Q28

RFF Research Topic Areas: (1) Forests, (2) Resource Policy

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1. INTRODUCTION

A large portion of the United States' timber resources has been managed by the federal government for most of the last century. The agencies that manage the federal forests have received much criticism during that time for having timber-sale policies that officially neglect economic concerns. Academics have shown that large welfare losses are imposed on society if the Forest Service (FS) and Bureau of Land Management (BLM) adhere to sustained-yield style policies that are price- and interest-rate-invariant.[1] Consumer groups have complained that price-insensitive harvest from federal timberland has at times contributed to wood-product price volatility, and small wood-processing mills have objected that it led to log shortages during periods of high demand, forcing their input costs to be unnecessarily high. This chorus of complaints focused on the fact that the allowable-cut planning systems used by the agencies are largely driven by timber inventories and biological growth rates. These planning systems, however, dictate only the total harvest that is permissible during ten-year periods. They do not control the year-to-year sales, much less the harvest.

Adams, Binckley, and Cardellichio (1991)[2] present the first challenge to the myth of price-insensitive harvests, focusing on the National Forests (NFs). They point out that, for many years, the system of long-term harvest contracts in the Western FS regions allowed firms to build up large stocks of uncut volume under contract (VUC), and estimate that firms harvest more from that stock when prices are high. They neglect, however, the role of sale fluctuations in determining the overall price elasticity of harvests out of the public timber inventory, adopting the common belief that short-run stumpage-sale fluctuations have been insignificant.

This paper shows that this bit of common wisdom is simply wrong, and that the pattern of stumpage sales can have a substantial impact on the price elasticity of harvest out of inventory. Even in the regions and years studied by AB&C, negatively-price-elastic sales could have dramatically reduced the overall harvest elasticity. Analysis shows that federal stumpage sales did not display much systematic net correlation with prices, positive or negative, in the period of 1951-1992. Yet at the regional level, the overall short-run price elasticity of timber harvest from federal lands was significantly positive during that time

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[1] See, for example, Berck (1979) or Nelson and Pugliaresi (1985).

[2] This set of authors will be referred to as AB&C.

period. This confirms that logging firms have behaved in the manner described and estimated by AB&C, and implies that their behavior was the primary non-zero component of overall harvest elasticity. Sales need not, however, have played such a neutral role in the stumpage market. The analysis shows that budget fluctuations may have had a strong effect on the year-to-year stumpage sold by the FS. If the agency's budget had been negatively correlated with stumpage prices, the price elasticity of federal harvests could have been severely damped, increasing short-run wood-product price volatility and causing hardship for local mills dependent on federal timber.

2. BACKGROUND

The National Forest System (NFS) contains about 28% of the nation's total timber volume, and 41% of its softwood timber volume. The forests are divided among administrative regions (see Table 1, below). Some forest-management decisions occur at the regional and national levels, but day-to-day decisions are made by the officials in charge of the individual forest units.[3] Tables 2 and 3 (following pages) indicate some of the differences between the regions.[4] The largest forests are found in Regions 1, 5, and 6, and there are large, valuable stands of old-growth softwood trees in Regions 5 and 6. In contrast, the forests in the Eastern regions, 8 and 9, were generally acquired by the federal government after a period of private ownership, and tend to be of less commercial importance. Because they grew up in a haphazard fashion on abandoned farmland or cut-over forestland, they are stocked with younger trees and less commercially valuable species.

The BLM manages small forests scattered throughout the public domain, but most of them are too small (and the data for them are too sparse) to be included in this study. The main forests under control of the BLM are in Western Oregon. The Oregon and California lands and the Coos Bay Wagon Road lands are close to NFs in Region 6. Like their neighbors, these forests contain large stands of old-growth Douglas fir.

The timber sale programs for these agencies are guided by five- or ten-year "allowable cut" calculations designed to keep harvests in line with long-run management goals. However, the amount of timber actually sold from a forest in any given year depends on the discretion of the official in charge of it, and the desire of firms to purchase what is offered. Table 4 reveals that annual sales have varied substantially relative to the average sale level, even if the data are broken up into several periods of time to account for long-run trends. In many cases, sales have varied more than harvests in the same region and time period.

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[3] This study will not include the NFs in Region 10, Alaska. Any analysis of the harvest patterns in that region would have to be qualitatively different from the analysis done here of the other regions. Thus the term "NFS" in the paper will refer only to Regions 1-6, 8 and 9. There was once a Region 7, but it was merged with Region 9 (primarily) in 1966.

[4] A board foot is a unit of lumber measurement equivalent to one foot long, one foot wide, and one inch thick. "MBF" stands for "thousand board feet."

Table 1: Forest Service Administrative Regions

Region 1 (Northern)	Region 2 (Rocky Mountain)	Region 3 (Southwestern)
Montana North Dakota Idaho (panhandle) South Dakota (NW corner)	South Dakota (except NW corner) Nebraska Kansas Colorado Wyoming (except West)	Arizona New Mexico
Region 4 (Intermountain)	Region 5 (Pacific Southwest)	Region 6 (Pacific Northwest)
Idaho (except panhandle) Utah Nevada Wyoming (West)	California Hawaii	Washington Oregon
Region 8 (Southern)	Region 9 (Eastern)	Region 10
Kentucky Virginia Tennessee North Carolina Mississippi Alabama Georgia South Carolina Florida Texas Oklahoma Arkansas Louisiana Puerto Rico	Maine Vermont New Hampshire New York Massachusetts Connecticut Rhode Island Pennsylvania New Jersey West Virginia Maryland Delaware Minnesota Wisconsin Michigan Iowa Illinois Indiana Ohio Missouri	Alaska

Table 2: Stock of Sawtimber on Forest Service Timberland (mill. board feet)

year	Region	Volume	% Softwood	Region	Volume	% Softwood
1952		179054	99.5		179256	98.7
1962		175967	99.5		174116	98.7
1977	NFS	162753	99.5	5	160913	98.2
1987		111494	99.6		192486	94.9
1992		91550	99.4		212919	96.1
1952		153942	99.8		424285	99.0
1962		163832	99.8		429152	98.8
1977	1	155681	99.9	6	392000	98.6
1987		161355	99.8		324689	100.0
1992		235000	68.5		324808	100.0
1952		60447	95.8		34020	58.0
1962		62705	95.6		46192	60.9
1977	2	69375	95.5	8	61964	58.3
1987		71685	95.3		74356	56.7
1992		71685	95.3		79925	52.3
1952		27509	97.2		8614	34.6
1962		28436	96.9		12713	34.6
1977	3	28337	96.9	9	19860	37.6
1987		38677	95.9		28231	37.4
1992		40235	95.9		29744	36.4
1952		12955	92.1			
1962		13426	91.9			
1977	4	12485	93.5			
1987		13232	93.1			
1992		13442	93.2			

Source: Powell, et al. (1993).

Table 3: Percent of Forest Service Sawtimber Stock in Various Diameter Classes

Region	Year	Diameter Class (inches)			
		9-12.9	13-16.9	17-20.9	21+
1,2,3,4	1952	23.4	23.0	19.1	34.5
	1962	26.1	24.5	19.4	30.0
	1977	28.5	24.7	18.1	28.7
	1987	28.8	26.2	17.8	27.2
	1992	29.3	26.8	18.0	25.8
5	1952	3.5	5.1	6.6	84.9
	1962	3.8	6.1	7.6	82.5
	1977	4.8	8.5	10.3	76.4
	1987	7.9	10.9	12.1	69.1
	1992	8.1	11.0	12.0	68.9
6	1952	8.4	9.0	10.4	72.1
	1962	9.1	10.8	11.7	68.4
	1977	10.6	12.8	13.3	63.3
	1987	13.1	16.2	15.6	55.1
	1992	13.9	16.9	15.7	53.6
8	1952	47.4	33.2	13.3	6.1
	1962	44.9	34.6	14.4	6.1
	1977	43.1	34.4	15.3	7.1
	1987	40.4	34.2	16.7	8.7
	1992	38.9	34.7	17.0	9.3
9	1952	49.3	27.7	13.3	9.7
	1962	51.2	27.3	13.0	8.6
	1977	52.3	27.4	12.5	7.8
	1987	50.3	28.2	12.9	8.6
	1992	49.1	27.8	13.3	9.8

Source: Powell, et al. (1993).

Table 4: Coefficients of Variation for Forest Service Activities

	All Years: 1950-93		1950-60		1961-82		1983-93	
Region	CVs	CVh	CVs	CVh	CVs	CVh	CVs	CVh
1	.35	.31	.35	.32	.23	.22	.32	.23
2	.35	.24	.41	.19	.35	.20	.23	.19
3	1.08	.24	1.62	.11	.25	.19	.29	.25
4	.34	.27	.47	.34	.26	.16	.22	.18
5	.36	.35	.42	.36	.15	.20	.37	.32
6	.33	.30	.35	.28	.08	.17	.49	.35
BLM	.35	.38	.31	.33	.16	.27	.43	.33
8	.25	.28	.25	.22	.13	.13	.16	.21
9	.22	.25	.22	.19	.16	.09	.12	.13
NFS	.28	.27	.36	.26	.08	.14	.33	.37

NOTES:
1) The coefficient of variation of a variable, CV, is the standard deviation divided by the mean.
2) CVs = coefficient of variation for sales during this time period.
3) CVh = coefficient of variation for harvests during this time period.

Neither of these agencies has logging or timber-processing capabilities. Hence, all harvests from the public forest lands are carried out by private firms. The agencies auction off the right to harvest a stand of trees through a more-or-less competitive bidding process. The resulting contracts are quite complex, and vary in nature between regions. In the Western regions of the FS, the contract specifies the stumpage price to be paid at the time of harvest. Before the 1980s, firms paid very little money up-front; final log measurement and payment was made when the logs were removed. The contract also states the number of years in which the firm can carry out its harvesting activities. The median contract length in these regions during the 1960s and 70s was about four years.[5] BLM contract procedures are similar, though their contracts establish a lump-sum payment to be made either immediately, or in installments for longer contracts. These sale mechanisms made it possible for firms in the West to maintain VUC stocks that were several times greater than annual harvest levels for many years.

[5] AB&C (1991), p. 76. Note that some contracts are extremely long. One such sale appears as an outlier in the data for Region 3; it was a huge 25-year pulpwood contract. We will use a dummy to control for the presence of this unusual sale in Region 3.

A speculative bubble in Western stumpage prices burst at the start of the 1980s, leaving many firms holding contracts for stumpage that were too expensive to warrant harvest. VUC levels rose to an unprecedented high. Within a few years, the government created special provisions for firms to get out of these contracts. It also tried to ensure that such an event would not happen again by mandating changes in the contracting practices of the FS. The results were that harvest default penalties rose, more payment was required up-front, sale sizes became smaller, and contract lengths fell. These changes were phased in, beginning in 1982.[6] As a result, the amount of uncut volume under contract remaining at the fiscal year end fell after 1982, most dramatically in the West. However, the change in contract practices was accompanied by an independent fall in total annual sales. Hence, the sale-to-VUC ratio in the West displays little trend in the period studied here; that ratio has only risen in more recent years. The Eastern regions, like the BLM, establish in their contracts a lump-sum payment. Relative to the Western regions of the FS, their sales are smaller (if only because they do not have much mature timber in one place at any point in time) and their contracts are shorter (especially in Region 8). Hence, the administrative changes of the early 1980s had relatively little impact in these areas.

There have been broad changes in the legislative mandate handed to the FS since 1950, however, which may well have affected all of its regions.[7] The Multiple-Use Sustained-Yield Act was passed in 1960. It added forage, recreation, and wildlife to the list of resources that should be fostered in the NFs (which previously included only watershed capabilities and timber). It also directed the FS to follow a policy of "sustained yield," though the precise nature of such a policy was undefined. The concept of sustained yield was refined under the National Forest Management Act of 1976 (NFMA). The NFMA also implied that the yield obtained ought to be the maximum volume possible, directing the FS to harvest only trees that have reached their "culmination of mean annual increment of growth."[8] This piece of legislation set down strict guidelines for when clear-cutting is, and is not, acceptable, and described conditions under which timber stands ought not to be harvested at all. Finally, it strengthened and expanded the planning process that was started by the Classification and Multiple Use Act. Long-run forest-management plans are supposed to be formulated at several administrative levels of the FS, and to be updated every five or ten years. The first round of plans was to have been completed by 1985. However, as we can see from Table 5 (below), most forest units did not have final plans until well after that deadline. In Regions 5 and 6, it is likely that the planning process did not begin to bind FS actions until well after 1989, for most of the plans that existed then were entangled in appeals.

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[6] See Muraoka and Watson (1983) and (1986), for a complete exposition and analysis of these changes.

[7] BLM management of the O&C lands has been driven by sustained-yield objectives since well before World War II. The few pieces of legislation since 1950 that affected the BLM were aimed largely at their role in managing the remaining public domain lands.

[8] This is the optimal harvesting policy only if one's objective is to maximize the total volume of wood obtained from a forest, and not the social surplus we obtain from that wood.

Table 5: Number of Final Forest Plans Completed by October 1

Region	Total # of units	1984	1985	1986	1987	1988	1989
1	13	0	0	5	13	13	13
2	12	9	10	12	12	12	12
3	11	1	1	3	9	10	11
4	16	3	4	9	12	12	14
5	18	0	0	1	1	6	9
6	19	0	0	0	0	0	4
8	17	6	7	15	17	17	17
9	15	1	1	10	14	15	15

NOTES:
1) The forests are broken into "units" for administrative purposes. Forest-level plans under the NFMA are designed around those units.
2) This table includes only information up to 1989.

Source: Joint Oversight Hearing on the National Forest Planning Process as Provided in the National Forest Management Act of 1976. S. Hrg. 101-553, October 25, 1989.

Sales and harvests in Regions 5 and 6 were, however, affected seriously by the conflict over the Northern spotted owl. The owl was formally listed in 1990 as "threatened" under the Endangered Species Act of 1973. The listing itself was preceded and followed by a series of lawsuits brought by environmental groups to halt logging in the federal old-growth forests.[9] These suits resulted in a number of restraining orders that restricted sales and harvests in Regions 5 and 6 and in the BLM's Pacific-Northwest old-growth forests. Various orders and injunctions were binding in 1989, and then from 1990 until mid-1994.

3. FRAMEWORK

AB&C construct a model of a logging firm's decision of whether to harvest a contract in the current year, or to delay harvest. Their model indicates that the fraction of total VUC harvested in a given year is a function of the interest rate and of the ratio of the current value of the stumpage to the average price established in the contracts that compose the VUC. Using data on three Western regions for 1969 through 1987, they find that

$$\frac{d\left(\frac{H_t}{VUC_t}\right)}{d\left(\frac{P_t}{BP_t}\right)} > 0 \tag{1}$$

[9] For a chronology of events in the spotted-owl conflict during this time, see *Northwest Forests Management, Planning, Productivity Improvement, and Protection Act,* House Report 102-1039 Part 1, pp. 73-94.

where P is the current value of the stumpage, BP is a weighted average of the bid prices for the stumpage included in VUC, and t indexes the year. An implication of this result is that

$$E_{HV} \equiv \frac{P_t}{\left(\frac{H_t}{VUC_t}\right)}\left(\frac{d\left(\frac{H_t}{VUC_t}\right)}{dP_t}\right) > 0 \tag{2}$$

Their model is a good description of logging-firm behavior. The results imply that the ability of firms to decide when to harvest VUC may influence the elasticity of harvest from the federal sawtimber inventory, E_{HI}, to be positive. However, the story is not yet complete; E_{HI} will be affected by the patterns of actions taken both by firms and by the relevant managing agency.

The sawtimber inventory, I_t, is fixed at the beginning of period t, according to

$$I_t = I_{t-1} - H_{t-1} + G_{t-1} \tag{3}$$

where G is the amount of timber generated through natural growth and re-planting in a given year. The amount of timber that firms have available for harvest, however, is affected by the amount of timber sold by the agency, S_t[10]:

$$VUC_t = VUC_{t-1} - H_{t-1} + S_t \ . \tag{4}$$

This formulation assumes that volume sold is immediately available for the current period's harvest.

We have seen that the annual volume sold by each agency from each region is not constant. The price elasticity of sales out of inventory, E_S, may well be non-zero, where E_S is defined as:

$$E_s \equiv \frac{d\left(\frac{S_t}{I_t}\right)}{dP_t}\frac{P_t}{\left(\frac{S_t}{I_t}\right)} = \frac{dS_t}{dP_t}\frac{P_t}{S_t} \ . \tag{5}$$

With these definitions in hand, simple algebra reveals that E_{HI} depends intuitively on E_{HV} and E_S:

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10 In fact, VUC will also be affected by the annual amount of timber in defaulted contracts. We will generally ignore that factor, both because defaults are not common and because we do not have data on defaulted volumes.

$$E_{HI} \equiv \frac{P_t}{\left(\frac{H_t}{I_t}\right)}\left(\frac{d\left(\frac{H_t}{I_t}\right)}{dP_t}\right) = E_{HV} + \left(\frac{dS_t}{dP_t}\right)\frac{P_t}{VUC_t} = E_{HV} + E_S\,\frac{S_t}{VUC_t} \quad (6)$$

The extent to which E_S affects E_{HI} depends on the relative size of S toVUC, not on the absolute level of VUC. If VUC stocks are very large relative to annual sales, then the second term of the expression becomes unimportant, implying that $E_{HI} \approx E_{HV}$. In this case, estimates of E_{HV} give us a good idea of how sensitive the rate of harvest out of total agency inventory is to price. At the other extreme, firms may end each period with volumes of left-over VUC that are tiny relative to the next period's sales. Then we have $VUC_t \approx S_t$ and $E_{HI} \approx E_{HV} + E_S$. Under these circumstances, if we want to know whether the pattern of harvests from federal timberland is contributing to price volatility, we must consider the behavior of annual sales. The behavior that obtains depends on the agencies' objectives, the ability of firms to influence the quantity of sales transacted, and the presence of budget constraints on the agencies' actions; a number of scenarios are possible.

First, it has been argued that the explicit management concerns of the BLM and FS revolve entirely around biological quantities. For example, they may want to maximize long-run physical timber yields subject to the constraint that certain amounts of non-timber amenities are provided. An agency with such an objective will have a price-invariant desired annual-sale level. The quantity of stumpage actually sold may be constrained in some years by firms' willingness to buy,[11] causing sale patterns to reflect the price elasticity of demand. However, if "no-bid" sales are not common, even transacted sales will be price invariant.

Second, if an agency is interested instead in the well-being of wood-product consumers and the mills that are dependent on federal timber, then the lobbying efforts of those groups indicate that the agency should act to have harvests from its lands be positively price-elastic.[12] If, for example, sales are not tiny relative to VUC, and if the agency wants E_{HI} to be greater than E_{HV}, the agency must arrange to have E_S be positive.

Third, the agency's dominant goal could be a form of budget-and-influence maximization. In that case, it should time more of its sales to occur when prices are high. That strategy is likely to increase the present value of revenues, (though its impact may be small due to price-adjustment clauses in the FS's multi-year contracts) and there is some indication that, at least for the FS, budget appropriations are linked to the revenue that accrues

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[11] It is unlikely that a sustained-yield maximizing agency would mind small year-to-year fluctuations in the amount it succeeds in selling, as long as sales meet its long-run goals.

[12] Note that in the unlikely event that the agencies are most concerned about the welfare of other forest land owners, the implications of this paragraph are reversed. The maximum PDV of an agent's forest is higher if there is a mean-preserving spread in stumpage prices. See Brazee and Mendelsohn (1988) for details.

to the Treasury from the timber program.[13] If this hypothesis about the agency obtains, E_S should be positive regardless of the amount of VUC available to firms.

Changes in budget allowances may act as more than a motivating force to the FS, however. The fourth possibility to consider stems from the fact that preparing stumpage sales requires substantial effort and resources from the agency. Thus, in years when the budget is small, the agency may not be able to offer as much volume for sale as it would like. If this mechanism is an important factor in the annual variation in sales, then the E_S we observe will depend on the correlation between budget and price.

4. ESTIMATION

The goals of the analysis are threefold. It estimates E_{HI}, in order to evaluate the impact of federal harvest patterns on wood-product price volatility. It seeks to quantify E_S, enabling us to evaluate the historical and potential impact of federal stumpage sale patterns on E_{HI}. Finally, it explores any link between FS sales and the budget for the National Forest System (NFS)[14] in an attempt to understand the mechanism that determines E_S. To accomplish these goals, three sets of regressions were run on data for 1951-1992. Each set includes ten equations: one for each FS region (except Region 10), one for the BLM's lands in Western Oregon, and one for the entire continental NFS.

The dependent variables are ln((harvest/inventory)*100) and ln((sales/inventory)*100). The nation's timber inventory is measured at infrequent intervals (see Appendix I for details about data sources). Since no data exist on actual annual growth of the federal timber inventory, linear interpolation is used for the intervening years. Note that the resulting inventory data correspond closely to the agencies' own understanding of their timber stocks. Including inventory here helps to calibrate the equations between regions, since the level of a region's annual sale is closely tied to the inventory volume in that region. The results are not sensitive to that inclusion.

The main explanatory variables, as discussed in Section 3, are price and NFS budget (see Appendix II for details on the price variable). The coefficients reported for price and budget can be interpreted as elasticities, since they enter in natural-log form. Data are unavailable for the budget that corresponds to the BLM's management activities in Oregon, so budget variables will be absent from the analysis of BLM sales. The current interest rate is included in the equations because it plays a role in every theory of forest-management policy and behavior, optimal or otherwise.[15] Intuition from capital theory might lead us to expect its coefficient to be positive. On the other hand, interest rates are a determinant of the demand

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[13] Frome (1971), p. 77.

[14] Note again that we exclude Region 10 from our working definition of the NFS. In fact, the main FS units in Region 10 have separate line-items in the FS budget.

[15] For a background in classic Faustmann steady-state, optimal-rotation-age theory, see Bowes and Krutilla (1985). For a dynamic theory of timber markets, see Brazee and Mendelsohn (1990). For examples of how interest rates might affect the harvest decisions of the firms, see AB&C (1991) and Rucker and Leffler (1988).

for wood products in a way that might make its coefficient negative. Its sign in theory is often dependent on the relative magnitude of other variables. Therefore, we have no solid expectations for its sign. Interest rate is linear in the regressions, so the coefficients on it should be interpreted as the proportional change induced in the percent harvested (or sold) by a one-percentage-point change in the interest rate.

Each set of regressions was estimated with a spline (see Appendix IV for details). This construction allows for a piecewise-linear trend in the data; both the constant term and the coefficient on the trend shift. The coefficients on "trend1," "trend2," and "trend3" give the slope of the first, second, and third segments of the spline, respectively; the parameters on "const1," "const2," and "const3" are the constant terms for the three periods. The spline has two roles to play. First, it controls for unobservable changes in long-run management objectives. The legislation described in Section 2 might have induced some changes. Public-timber-policy lore describes a shift in BLM and FS attitudes[16] in the 1950s, resulting in a build-up of the timber programs in the Western regions. And in recent years, wilderness withdrawals (due to roadless-area reviews) and conflicts with endangered species have restricted the public-forest land base available for timber harvest. Second, the spline captures any changes in effective inventory that are not reflected in the data. For example, some forests in the West were largely inaccessible in 1950, due to a lack of roads and a small number of conveniently-located processing mills; the effective inventory (as a fraction of estimated inventory) was probably growing throughout the 1950s. Conversely, Tables 2 and 3 show that softwood and old-growth forest stands have been disproportionately depleted in some regions. This implies that effective inventory may have been a declining fraction of estimated stock during the most recent period.

In all equations except those for the Eastern regions, the time periods covered by the three spline segments are as follows: 1951-1960, 1961-1982, and 1983-1992. The first break corresponds to the passage of the MUSYA; the second corresponds to the beginning of changes in sale procedures. For Regions 8 and 9, the second break occurs at 1984, the year when the NFMA planning procedure began to bind in those regions, since the changes of 1982 are not likely to have had an impact in the East. These dates are convenient because the resulting divisions correspond roughly to times when other non-legislated management changes were occurring. Use of them also forestalls the temptation to choose years that provide the "best" results. The events that mark the break years, however, are unlikely to have produced discrete and instantaneous changes in sale and harvest behavior, due to multi-year contracts and the lagged nature of the administrative process that generates sales. For this reason, it is important to impose the basic spline restriction that the line segments meet each other at the "knot" years. Experimentation with the regressions showed that failure to do

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[16] The increase in demand for timber triggered by WWII, and then by the housing boom following the soldiers' return, convinced the BLM and FS that their custodial role in the Western forests should be replaced by "wise-use" of the resources.

so yields results with unreasonable jumps at the breaks.[17] Further experimentation indicated that inclusion of a shifting trend is important to the results, especially to the early and late periods. The strong trends in harvests and sales during those periods happened to run against trends in price. Thus, failure to allow for the trends biases the estimates of firm and agency behavior.

The analysis allows for structural change in the coefficients on price, interest rate, and budget; the change is allowed to occur at the knot-point years in the spline. Also, two dummy variables were included in some of the equations to control for special, discrete, events. A dummy for years with spotted-owl-related court orders, "owl," is included for Regions 5 and 6, the BLM, and the NFS, and a dummy for the big 25-year pulpwood sale in Region 3, "d3", is included in the equation for sales in that region.

The regressions were run using Zellner's "seemingly unrelated regression" (SUR) estimation procedure. This was chosen because it is efficient relative to equation-by-equation OLS. The point estimates do not change much when SUR is used instead of OLS (those results are not presented here). However, as expected, the standard errors are lowered somewhat by using the system estimator. In each set of regressions, a Lagrange-multiplier test suggested by Breusch and Pagan[18] rejects the hypothesis of independent error terms at the .00 significance level.

5. DISCUSSION

The estimates of E_{HI} in Table 6 (following page) indicate that E_{HI} is positive and significant in most regions and time periods; only the estimates of E_{HI} for Regions 3 and 8 are largely insignificant, but even there E_{HI} became positive and significant in the last period. In contrast, real interest rates have had a small net impact on the rate of harvest from public forest timber inventories. In Regions 3 and 9 it had a statistically significant but small effect in period 2; only since the early 1980s has it entered with a coefficient of any importance, and then only in the Pacific regions.

The spline components reveal that harvests have been fluctuating around strong trends. Most equations (except those for Regions 3 and 9) display a strong build-up of harvest activity in the first period. The percent of inventory that is harvested seems to level off after 1960, and even to fall gradually in some regions; the decline is more widespread and rapid in the last period. The late-period decline occurs in addition to the reductions of harvests due to the spotted owl conflict. The court orders reduced the percent of inventory harvested in Region 6 by 36% during the affected years (a reduction that is proportionately reflected in the NFS overall). The orders had a smaller (even insignificant) impact on harvests from BLM lands and NFs in California, perhaps because the Region 6 forests were the primary targets of the courts.

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[17] Note that under the restrictions, the constant terms for the first and third periods are not estimated as coefficients in the regressions; they are calculated using the equations for the restrictions.

[18] See Greene (1990), p. 515.

Table 6: Harvest Regressions

	NFS	Reg. 1	Reg. 2	Reg. 3	Reg. 4	Reg. 5	Reg. 6	BLM	Reg. 8	Reg. 9
ln(P)1	.228 * (.075)	.089 (.084)	.290 * (.103)	.018 (.110)	.375 * (.102)	.251 * (.082)	.168 * (.065)	.475 * (.141)	.320 (.205)	.358 * (.157)
ln(P)2	.278 *† (.071)	.178 *† (.079)	.293 * (.099)	.109 † (.108)	.387 * (.099)	.329 *† (.077)	.226 *† (.057)	.560 *† (.131)	.300 (.203)	.349 * (.155)
ln(P)3	.425 *† (.085)	.271 * (.115)	.386 * (.122)	.232 ** (.139)	.440 * (.117)	.508 *† (.104)	.464 *† (.076)	.773 *† (.152)	.373 **† (.209)	.425 *† (.157)
IRate1	.002 (.011)	.021 (.017)	-.003 (.015)	-.003 (.017)	-.003 (.013)	-.011 (.015)	.005 (.012)	.002 (.018)	-.001 (.011)	-.002 (.008)
IRate2	-.003 (.007)	.004 (.010)	.010 (.009)	-.022 * (.011)	-.004 (.008)	-.009 (.010)	-.002 (.008)	-.004 (.013)	.001 (.006)	.019 *† (.005)
IRate3	-.040 * (.020)	-.021 (.032)	-.017 (.028)	-.041 (.032)	-.010 (.025)	-.057 * (.028)	-.066 *† (.022)	-.071 *† (.033)	-.008 (.021)	-.016 † (.016)
trend1	.067 * (.015)	.061 * (.024)	.037 ** (.021)	.016 (.024)	.099 * (.019)	.107 * (.022)	.065 * (.018)	.095 * (.025)	.039 * (.016)	.005 (.012)
trend2	-.010 *† (.004)	-.018 *† (.006)	-.004 † (.006)	-.021 * (.007)	-.004 † (.005)	-.014 *† (.006)	-.005 † (.005)	-.018 *† (.007)	-.005 † (.004)	-.026 *† (.003)
trend3	-.063 *† (.020)	-.078 *† (.034)	-.043 (.029)	-.049 (.030)	-.062 *† (.026)	-.116 *† (.031)	-.061 *† (.022)	-.065 ** (.033)	-.090 *† (.020)	-.049 * (.015)
const1	-1.87	-1.48	-2.52	-.170	-1.76	-2.32	-1.62	-3.96	-1.63	-.890
const2	-1.17 * (.377)	-.765 ** (.401)	-2.16 * (.518)	-.155 (.495)	-.905 * (.537)	-1.24 * (.364)	-.983 * (.333)	-2.94 * (.728)	-1.24 (1.25)	-.609 (1.01)
const3	.477	1.09	-.942	1.04	1.14	1.92	.753	-1.51	1.57	.163
owl	-.178 * (.066)	-	-	-	-	-.115 (.093)	-.362 * (.101)	-.238 (.147)		

NOTES:
1) Dependent variable: ln((harvest/inventory)*100)
2) Numbers in parentheses are standard errors.
3) * indicates significantly different from zero at the 5% level; ** indicates significant at the 10% level
4) † indicates difference between this coefficient and that from the previous time period is significant at the 10% level, at least (relevant for price, interest rate, and trend).
5) Sample period: fiscal years 1951-1992.

The good news from these regressions is that harvests from the public timber inventory were positively price elastic in most regions and time periods. We turn now to Table 7 (below) to examine the patterns in stumpage sales, obtain estimates of E_S, and begin the process of determining the contribution of stumpage sale patterns to that elasticity.

The trends in sales mirror those we saw in the harvest regressions, though both the early rise and the later fall in sales are stronger in most regions than the corresponding movements in harvests. The impact of the spotted-owl court orders also seems to have been greater on sales than on harvests. Firms were clearly translating some of the sales of the 1950s into VUC stocks, and then drawing down their VUC during the 1980s in order to resist the decline in sales.

Table 7: Sales Regressions

	NFS	Reg. 1	Reg. 2	Reg. 3	Reg. 4	Reg. 5	Reg. 6	BLM	Reg. 8	Reg. 9
ln(P)1	-.002 (.082)	-.079 (.099)	.008 (.180)	-.044 (.189)	-.135 (.201)	.029 (.116)	-.106 (.091)	-.113 (.235)	-.048 (.153)	.583 * (.249)
ln(P)2	.000 (.079)	-.002 † (.094)	-.015 (.176)	-.091 † (.186)	-.121 (.195)	.090 (.113)	-.087 (.082)	-.030 (.218)	-.076 † (.152)	.586 * (.247)
ln(P)3	.150 † (.092)	.143 (.133)	.099 (.216)	.100 (.234)	-.083 (.229)	.327 *† (.148)	.202 **† (.101)	.435 **† (.252)	-.040 (.156)	.640 * (.249)
IRate1	-.007 (.010)	-.001 (.018)	.018 (.024)	-.062 * (.025)	-.022 (.024)	-.001 (.019)	-.001 (.013)	.010 (.028)	.002 (.008)	-.027 * (.013)
IRate2	.000 (.006)	.008 (.011)	.014 (.015)	-.006 (.017)	.004 (.014)	-.004 (.012)	-.007 (.010)	-.011 (.021)	-.004 (.004)	.021 *† (.007)
IRate3	-.054 *† (.018)	-.038 (.034)	-.022 (.046)	-.063 (.049)	-.003 (.046)	-.099 *† (.035)	-.105 *† (.024)	-.189 *† (.052)	-.007 (.015)	-.010 (.025)
trend1	.097 * (.014)	.056 * (.026)	.076 * (.034)	.106 * (.040)	.125 * (.033)	.108 * (.027)	.090 * (.019)	.089 * (.040)	.049 * (.011)	-.009 (.019)
trend2	.002 † (.004)	-.018 *† (.007)	-.006 † (.009)	-.007 † (.011)	-.013 † (.009)	.001 † (.007)	.010 **† (.005)	-.009 † (.011)	.001 † (.003)	-.028 * (.004)
trend3	-.086 *† (.018)	-.119 *† (.038)	-.065 (.048)	-.123 *† (.046)	-.040 (.046)	-.159 *† (.041)	-.113 *† (.026)	-.198 *† (.054)	-.082 *† (.014)	-.049 (.025)
const1	-.734	-.554	-1.24	-.215	.814	-1.30	-.294	-.754	.626	-2.16
const2	.123 * (.412)	.108 *8 (.475)	-.491 * (.906)	.808 (.846)	2.05 (1.05)	-.337 * (.516)	.429 (.468)	-.125 (1.21)	1.06 (.934)	-1.98 (1.61)
const3	2.84	3.24	1.34	4.39	2.90	4.63	4.25	5.99	3.79	-1.29
d3				1.91 * (.296)						
owl	-.401 * (.059)					-.344 * (.147)	-.878 * (.135)	-1.08 * (.261)		

NOTES:
1) Dependent variable: ln((sales/inventory)*100)
2) Numbers in parentheses are standard errors.
3) * indicates significantly different from zero at the 5% level; ** indicates significant at the 10% level
4) † indicates difference between this coefficient and that from the previous time period is significant at the .10 level, at least (relevant for price, interest rate, and trend).
5) d3 is a dummy = 1 if and only if region is 3 and fiscal year is 1960.
6) Sample period: fiscal years 1951-1992.

The real interest rate also seems to play a similar role in the sales regressions that it does in the harvest analysis; it was only a strong factor during the third period in the Pacific forests (and hence in the overall NFS). Real interest rates seem to have a larger impact on sales than on the fraction of inventory harvested; this indicates that the VUC harvesting mechanism dampens the effect. The negative sign of the coefficients implies that the interest rate may be acting as a signal of wood-product demand conditions, and that sales in those areas were positively correlated with that demand during the third time period.

That pattern is echoed in the estimates of E_S. During period 3, E_S was positive and significant in Regions 5 and 6 and on the BLM's lands. Region 9 sales were positively related to price as well, though the relationship there actually holds for all three time periods. However, in most regions and time periods, and for the NFS overall, E_S is statistically insignificant. It seems that any correlation between federal stumpage sales and price has occurred only in a few regions and time periods, if at all.

Some implications of these results are presented in Table 8 (below). E_S has made an important, positive contribution to E_{HI} in Region 9 since 1951. Furthermore, sale patterns in the Pacific forests bumped up E_{HI} in that area during recent years. Otherwise, E_S has not affected the price-elasticity of harvest out of inventory. For the vast majority of regions and time periods, E_{HI} is exactly equal to the value of E_{HV} that is implied by the regression results. This does not mean, however, that E_S could not have had a substantial impact on E_{HI}. The last column of Table 8 gives us a hint of what E_{HI} might have been if E_S had been substantially negative (but firm behavior remained the same). In all regions, E_{HI} would have been substantially depressed. Even for the regions and years AB&C studied, the presence of E_S equal to -.5 would have lowered E_{HI} by at least half.

Since VUC has fallen relative to sales[19] (in at least some regions) as a result of the administrative changes of the 1980s, E_S now has even more potential to affect E_{HI}. Even if federal timber has become a smaller force in national timber markets, it remains locally important to some small mills due to transportation costs. This gives us an incentive to understand the mechanisms that drive the connection between federal stumpage sales and price. The regressions in Table 10 (below) represent an attempt to increase our understanding by exploring the connection between FS timber sales and NFS budget constraints (data constraints prevent a similar understanding of the BLM). The interpretation of these results takes into account the correlations between budget and price (see Table 9, below), and the fact that the budget variable may, in some periods, mimic the trend.[20]

Inclusion of the NFS budget variable into the sales regressions leaves some features of the results unaffected. The coefficients on the interest rate, the owl dummy, the Region-3-outlier dummy, and the segments of the spline are much the same as they were in Table 7 (though a few first-period-trend coefficients do change with the introduction of the budget variable, probably due to correlation between that trend and the budget). The equation for BLM sales is unchanged, indicating that there is no serious new mis-specification in the other equations.[21]

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19 Some such mills have gone out of business precisely because they relied on timber from federal lands, and the size of the federal timber program has shrunk dramatically.

20 Removing the interest rate from the regressions displayed in Tables 6, 7, and 9 does not substantially affect the other results, despite its correlations with price and budget.

21 Such "contagious mis-specification" is a common phenomenon with system estimators.

Table 8: Estimates of E_{HV}, Contribution of E_S to E_{HI}

Region	Period	S/VUC actual	E_{HV} estimate	E_{HI} actual	E_{HI} if E_S = -.5
1	1	.29	.00	.00	-.14
	2	.30	.18	.18	.03
	3	.23	.27	.27	.16
2	1	.42	.29	.29	.08
	2	.22	.29	.29	.18
	3	.18	.39	.39	.29
3	1	.25	.00	.00	-.12
	2	.09	.00	.00	-.04
	3	.09	.23	.23	.19
4	1	.64	.38	.38	.05
	2	.33	.39	.39	.22
	3	.32	.44	.44	.28
5	1	.18	.25	.25	.16
	2	.27	.33	.33	.19
	3	.25	.43	.51	.30
6	1	.21	.17	.17	.06
	2	.28	.23	.23	.09
	3	.24	.42	.46	.30
BLM	1	.64	.48	.48	.15
	2	.39	.56	.56	.36
	3	.32	.63	.77	.47
8	1	.55	.00	.00	-.28
	2	.45	.00	.00	-.22
	3	.38	.37	.37	.18
9	1	.59	.02	.36	-.28
	2	.33	.16	.35	-.01
	3	.28	.24	.43	.10
NFS	1	.26	.23	.23	.10
	2	.27	.28	.28	.14
	3	.24	.43	.43	.31

NOTES:

1) S/VUC is the average of the ratio of sales to the VUC variable defined in Equation 4. See Appendix III for details about the VUC data.
2) E_{HV} is calculated using estimates of E_S and E_{HI} (Tables 6 and 7) and Equation 6. Any estimates of E_S and E_{HI} that were not statistically significant were set to zero.
3) The last column gives an estimate of E_{HI} with E_{HV} held constant but E_S changed to -.5 in all regions and time periods.

Table 9: Correlation Coefficients

Variables Correlated	All years: 1951-92	1951-60	1961-82	1983-92
Price, Budget	.21	-70	.09	.42
Price, Interest Rate	-.29	-.19	-.53	-.57
Budget, Interest Rate	.44	.35	-.09	-.38

Table 10: Sales Regressions with Budget

	NFS	Reg. 1	Reg. 2	Reg. 3	Reg. 4	Reg. 5	Reg. 6	BLM	Reg. 8	Reg. 9
ln(P)1	.213 (.274)	-.326 (.537)	1.83 * (.833)	.297 (.747)	1.90 * (.857)	1.31 * (.463)	-.498 * (.214)	-.087 (.271)	.709 ** (.400)	1.79 ** (.647)
ln(P)2	.027 (.078)	.023 (.099)	-.069 † (.171)	-.105 (.202)	-.188 † (.188)	.092 † (.108)	-.017 † (.078)	-.007 (.251)	-.101 † (.157)	.622 **† (.253)
ln(P)3	-.095 (.337)	.453 (.470)	1.34 (.871)	-.462 (.726)	.427 (.872)	-.413 (.581)	-.918 *† (.264)	.475 **† (.287)	.437 (.438)	.969 (.754)
ln(B)1	.258** (.151)	.606 * (.302)	-.347 (.418)	-.117 (.420)	-1.00 * (.431)	.026 (.273)	.504* (.157)		-.338 ** (.191)	-.060 (.325)
ln(B)2	.328 * (.125)	.489 * (.266)	.407 † (.341)	.023 (.381)	-.115 † (.339)	.495 *† (.250)	.303 *† (.136)		.052 † (.113)	.542 **† (.189)
ln(B)3	.420 * (.172)	.390 (.281)	-.028 (.397)	.201 (.436)	-.310 (.403)	.732 * (.329)	.724 *† (.172)		-.174 (.198)	.396 (.341)
IRate1	-.005 (.009)	.004 (.018)	.018 (.023)	-.062 * (.026)	-.026 (.022)	-.006 (.017)	.003 (.011)	.009 (.029)	.001 (.008)	-.022 * (.012)
IRate2	-.002 (.006)	.004 (.011)	.007 (.014)	-.007 † (.018)	.004 (.014)	-.009 (.011)	-.003 (.009)	-.010 (.023)	-.004 (.005)	.017 ** (.007)
IRate3	-.051 *† (.016)	-.032 (.034)	-.026 (.044)	-.057 (.050)	-.008 (.043)	-.097 *† (.032)	-.115 *† (.021)	-.193 *† (.055)	-.009 (.015)	-.002 (.023)
trend1	.072 * (.023)	-.012 (.042)	.117 * (.057)	.112 ** (.061)	.237 * (.057)	.131 * (.042)	.025 (.026)	.090 * (.042)	.097 * (.028)	-.001 (.041)
trend2	-.015 *† (.007)	-.041 * (.015)	-.029 † (.019)	-.009 † (.022)	-.008 † (.019)	-.024 **† (.014)	-.002 (.008)	-.009 † (.011)	-.001 † (.006)	-.055 ** (.010)
trend3	-.074 *† (.022)	-.151 *† (.056)	-.170 *† (.079)	-.098 ** (.052)	-.075 (.074)	-.088 (.062)	-.104 *† (.022)	-.210 *† (.060)	-.079 *† (.014)	-.049 * (.025)
const1	-4.79	-6.23	-6.44	-.494	1.60	-7.75	-3.93	-.898	-.301	-9.29
const2	-4.01 * (1.59)	-5.96 ** (3.30)	-5.14 (4.30)	.590 (4.82)	3.81 (4.29)	-6.36 * (3.12)	-3.68 * (1.74)	-.004 (1.39)	.586 (1.78)	-8.80 ** (2.84)
const3	-2.15	-2.57	-.761	3.37	5.88	-4.39	-.528	6.22	3.15	-8.99
d3				2.04* (.293)						
owl	-.444 * (.065)					-.535 * (.169)	-.896 * (.113)	-1.02 * (.308)		

NOTES:
1) Dependent variable: ln((sales/inventory)*100)
2) Numbers in parentheses are standard errors.
3) * indicates significantly different from zero at the 5% level; ** indicates significant at the 10% level
4) † indicates difference between this coefficient and that from the previous time period is significant at the 10% level, at least (relevant for price, interest rate, and trend).
5) d3 is a dummy = 1 if and only if region is 3 and fiscal year is 1960.
6) Sample period: fiscal years 1951-1992.

Interpretation of the coefficient results for the budget and price variables is complicated by two potential problems. First, budget and price are strongly correlated in the first and third time periods (most notably the first); the regional estimates of price elasticity in particular show classic symptoms of multi-collinearity. Second, data are not available on the allocation of the NFS budget between regions.[22] As long as each region's share of the total budget does not fluctuate too dramatically, the budget-elasticities of sales estimated here may not be too biased on that account, but the region-level results are clearly less reliable than the results from the national-level equation. For these reasons, this discussion focuses primarily on the results from the equation for the whole NFS, and looks to the regional equations only for confirmation of the patterns found there.

Budget enters the equation for the whole NFS with a strong, positive sign in all periods; budget fluctuations do seem to induce fluctuations in the total quantity of stumpage sold. However, inclusion of budget in the equations yields estimated "structural" effects of price on sales (E_S^*) that differ from the "observed" E_S we saw in Table 7 when budget was omitted. Most notably, while E_S was estimated to be positive and significant in the third time period, E_S^* is not significantly different from zero in any time period. These findings are consistent with the hypothesis that budgets are a limiting factor in the amount of timber that regions are able to offer for sale in a given year. The positive third-period E_S found in Table 7 seems to have been due to omitted-variable bias caused by the positive correlation between price and budget in that time period.

At the regional level, we see echoes of the budget-constraint effect, especially in Regions 1, 5, 6, and 9. There is also some support here for the omitted-variable explanation for some of the positive price elasticities found in Table 7; the relationship between price and sales now appears even to be negative in period 3 for Regions 5 and 6. In period 1, E_S^* is occasionally positive and significant, but its sign is a bit mixed and its point estimates are sometimes difficult to believe (possibly a result of multicollinearity). Only in Region 9 does price really still appear to be positively correlated with sales once annual budget levels have been accounted for.

Taken together, the results may imply that, in the FS regions other than 9, there is no strong, consistent structural response of annual sales to stumpage prices. The patterns revealed here are consistent with the behavior of an agency that is largely worried about its biological management goals when deciding how much timber to sell in any given year, but which is constrained by its annual budget appropriations in how much timber it actually can offer for sale. Any positive correlation between sales and stumpage prices may have largely been the product of a fortunate positive correlation between budget and price.

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[22] These data are impossible to get for many years of the sample. The official budget is determined for the NFS as a whole. Each region receives a fraction of the funds based on rationing decisions made by top officials in the FS; the regional budget figures have only been preserved for relatively recent years. See Sample (1990) for more information on this process.

The FS chose to increase the level of sales during the 1950s; that expansion was probably able to proceed more rapidly during periods of high prices.[23] The resulting E_S^* was positive enough to counteract the negative E_S that would otherwise have been induced by the budget effect. During period 2, we have a classic picture of an agency that is simply offering sales at some biologically-determined, long-run level. "No-bid" sales were probably not important enough to push E_S^* away from zero, and any budget effect was not correlated with price. In the more recent time period, any fluctuating budget constraints acted to create a positive link between sales and price. This probably helped to counteract any regional negative E_S^* that was induced by shrinking the total size of the FS's timber program.

6. CONCLUSION

The presence of a VUC stock that is large relative to annual sales can help to ensure that the price elasticity of harvest from federal lands is positive, regardless of fluctuations in sales. As long as the price elasticity of sales is not significantly negative, such a stock enables the FS to foist short-run decisions about harvest timing onto profit-maximizing firms, while retaining the right to make long-run decisions about the provision of timber and non-timber amenities. From 1951 to 1992, this mechanism worked well in our federally-owned forests. The price elasticity of firms' harvest out of VUC was largely positive, while the overall correlation between sales and stumpage prices has been close to zero. The result has been that, controlling for trends, harvest from our public timber inventory has been positively price elastic in most regions of the country.

Sales were large enough relative to VUC, however, that if sales had been negatively correlated with price, the overall harvest elasticity would have been substantially reduced. Now, the potential for the price elasticity of sales to affect harvest elasticity is even larger than in the years studied by this paper (since VUC has fallen relative to annual sales). If agency budget constraints have a strong impact on the pattern of annual sales (as implied by some of the results of this paper), then any negative correlation between the NFS budget and wood-product prices could yield negatively price-elastic sales, causing supply problems for federal-timber-dependent mills during periods of high stumpage prices and contributing to wood-product price volatility.

[23] The federal forests had relatively few roads, and poorly developed links with private firms. Interest in FS sales would only be large during times when stumpage was valuable enough to compensate for the inconvenience.

APPENDIX I: DATA SOURCES

Data are available for 1951-1992 unless stated otherwise.

1) Volume of stumpage sold and harvested from FS lands, by region and fiscal year (mbf). Source: unpublished FS data.

2) Volume of stumpage sold and harvested from BLM lands in Western Oregon, by fiscal year (mbf). Sources: *Public Land Statistics*, various issues; unpublished communication with BLM's Oregon office; Clawson (1967).

3) Price indexes, monthly, seasonally unadjusted. Source: BLS, *Producer Price Indexes*, monthly 1950-1992.

All commodities (1982=100)
Metals and metal products (1982=100)
Fuel-oil, coal, and bottled gas (1982-4=100)
Softwood lumber (product code 0811) (1967=100)
Douglas fir lumber (product code 081101) (1967=100)
Southern pine lumber (product code 081102) (1967=100)
Other softwood lumber (product code 081103) (1967=100)
Hardwood lumber (product code 0812) (1967=100)

4) Annualized rate on 10-year Treasury bonds, monthly (percentage points). Source: CitiBase database.

5) Real GNP, quarterly (billions of 1987$). Source: National Trade Data Bank.

6) Unemployment rate, all civilian, annualized, monthly (percentage points). Source: CitiBase.

7) Resident population, by state, annual (thousands of people). Source: *Current Population Reports*.

8) New residential housing starts, monthly (thousands of units). Source: CitiBase database.

9) Stock of standing sawtimber by region, ownership, and wood type (mbf). Years available: 1952, 1962, 1977, 1987, and 1992, with interpolation for years between. Source: Powell, et. al. (1990).

10) Budget: direct program (converted to thousands of 1982$) allocated to the Forest Service for "National Forest protection and management." Includes "General Administration" after 1982. Does not include line items for Region 10. Source: *Budget of the United States* and *Appendix to the Budget of the United States*, fiscal years 1950-1991.

11) Logging and hauling costs for saw and veneer logs in selected regions, annual (1982$/mbf). Years available: 1950-1985. Source: Adams, Jackson, and Haynes (1988).

12) Softwood lumber non-wood production costs, by region and year (1982$/mbf). Years available: 1950-1985. Source: Adams, Jackson, and Haynes (1988).

13) Uncut timber volume under FS contract, by region and fiscal year (mbf). Years available: 1979-1993. Source: *Report of the Forest Service*, various issues.

14) Uncut timber volume under BLM contract in Oregon, (mbf). Years available: 1983-1992. Source: USDA (1994). Division into Western and Eastern Oregon accomplished using proportions derived from *Public Land Statistics*, various issues.

APPENDIX II: CONSTRUCTION OF PRICE VARIABLE

There are several variables one might use to represent the stumpage price faced by the agencies. First, the "price of sales" gives the average value of the stumpage placed under contract. AB&C use a weighted average of lagged and current values of this as a proxy for the bid price of the current VUC. However, this has a strong speculative component, since it is a price that will not be paid until the date when the firms chooses to harvest the timber. Furthermore, the use of price escalation/de-escalation clauses in some regions means that firms may end up paying a completely different price at the time of harvest.

Second, the "price of harvest" gives the average value of the stumpage harvested, and is used by AB&C as a proxy for the harvest value of timber. It is determined by the sale price of the volume under contract, as well as by firms' decisions of which parts of their stumpage portfolios to cut. Both of these prices are affected by the agencies' decisions, past and present, of what sort of stumpage to put up for sale, for tracts vary widely in quality, accessibility, and species mix.

These "prices" are difficult to interpret. Hence, this study uses a residual "stumpage" price that was constructed by subtracting logging, hauling, and processing costs from the price of lumber. The first step was to construct a lumber price for each region that reflects the composition of the forests there. That construction used monthly lumber price indexes for Douglas fir, Southern pine, "other softwood", "all softwood", and "all hardwood" lumber; the indexes were converted to prices in 1982$/mbf by using the prices that corresponded to the indexes in a base year. Data on the fraction of agency inventory in softwood (rather than hard), as well the species that tend to grow in different regions, were used to weight the five lumber-price series to form a composite lumber price for each region (the price used for the overall FS is a weighted average of "all softwood" and "all hardwood"). The resulting price series are aggregated by fiscal (rather than calendar) year.

Next, regional logging, hauling, and non-wood lumber-processing costs (1982$/mbf, by calendar year) were compiled. Those data series are available in Adams et. al. (1988); that publication, however, only has data for 1950-1985. For this paper, the missing years were filled in by regressing each available data series on real GNP growth, the national unemployment rate, the producer price indexes for fuel and metal products, regional population, and a spline with knots at the beginning of each decade (all aggregated by calendar year). The fit for these equations was very good; the R^2 statistics ranged between .83 and .98. The resulting parameter estimates and fiscal-year series of the explanatory variables were then used to predict costs for fiscal years 1950-1992. The final variable, called "P" or "price" in the text of this paper, varies by agency and region. It is the difference between the lumber price (as described above) and the total average processing costs in that region.

APPENDIX III: DATA ON UNCUT VOLUME UNDER CONTRACT

Data on left-over uncut volume under contract are available for all FS regions only for fiscal years 1980 to 1992, measured at the end of the previous fiscal year. Similar data are available for the BLM in Western Oregon from 1983 to 1992. Using the relationship expressed in Equation 4 and the data on fiscal year sales and harvests, these data were translated into VUC, as defined in this paper, and extrapolated back to 1950.

Recall that Equation 4 defined VUC as follows:

$$VUC_t = VUC_{t-1} - H_{t-1} + S_t \ . \qquad (4)$$

Fiscal-year sales were added to reported VUC_t to obtain VUC_t as defined in this paper. Then a simple re-arrangement of the equation shows how to derive VUC for the earlier years:

$$VUC_{t-1} = VUC_t + H_{t-1} - S_t \ . \qquad (7)$$

There are two sources of potential bias in this process. First, the presence of occasional contract default is neglected. If a firm breaks a contract by refusing to harvest the stumpage described therein, that stumpage volume ceases to be part of VUC, and goes back into the inventory pool to be re-offered for sale. Thus, if data were available on defaults, the extrapolation should be done according to

$$VUC^*_{t-1} = VUC_t + H_{t-1} + S_t + D_{t-1} \ , \qquad (8)$$

where D is the volume of stumpage defaulted. To the extent that default happens, extrapolation performed according to Equation 7 will underestimate the amount of VUC^*. Because of the cumulating nature of the process, any bias caused by neglecting default will be most pronounced in the earliest years.

The second source of bias is more serious, and lies in the nature of the original uncut volume data; they do not include uncut volumes from very long-term contracts. There was one such contract in Region 3 in 1960. The results of the initial extrapolation for Region 2 indicated that a similar contract was neglected in that region as well, most likely in 1963. The VUC data series for those regions were thus corrected to include estimates of the volumes of those sales.

Note that AB&C use different data on VUC for their study. Their source (various issues of USDA (1994)) can be traced back to 1965, but it has data only for Regions 1, 5, and 6.

APPENDIX IV: ECONOMETRICS

1) Splines: Many of the regressions in this study are run with a spline included in the specification. A spline allows for a piecewise- linear trend in the data. The slope of the trend can change after specified years, T_1 and T_2, but the line segments must match up at the "knot" years. For the purposes of this study, T_1 is 1960 in all equations. T_2 is either 1982 or 1984, depending on whether the region is Western or Eastern.

Since 1951 is the first year in the sample, let T = (year-1951) be the basic time index, $T_1^*=(T_1-1951)$, and $T_2^*=(T_2-1951)$. Also let:

$$\begin{aligned} &d_1 = 1 \text{ if } T \le T_1^*, && 0 \text{ otherwise} \\ &d_2 = 1 \text{ if } T > T_1^* \text{ and } T \le T_2^*, && 0 \text{ otherwise} \\ &d_3 = 1 \text{ if } T > T_2^*, && 0 \text{ otherwise} \end{aligned} \tag{9}$$

With Y as the dependent variable, the unconstrained specification would at this point be:

$$Y = \alpha_1 d_1 + \alpha_2 d_2 + \alpha_3 d_3 + \beta_1 d_1 T + \beta_2 d_2 T + \beta_3 d_3 T \ . \tag{10}$$

However, this specification does not rule out jumps in the fitted value of Y right after years T_1 and T_2. In order to do so, two constraints are imposed:

$$\begin{aligned} &1) \quad \alpha_1 + \beta_1 T_1^* = \alpha_2 + \beta_2 T_1^* \\ &2) \quad \alpha_2 + \beta_2 T_2^* = \alpha_3 + \beta_3 T_2^* \ . \end{aligned} \tag{11}$$

Combining the basic specification with the constraints gives us the following final equation:

$$Y = \alpha_2 + \beta_1 \left[d_1\left(T - T_1^*\right)\right] + \beta_2 \left[d_1 T_1^* + d_2 T + d_3 T_2^*\right] + \beta_3 \left[d_3\left(T - T_2^*\right)\right] \tag{12}$$

The expressions in brackets are referred to respectively as trend1, trend2, and trend3 in the tables of regression results. The constant terms are referred to as const1, const2, and const3. Only the coefficient on const2 is directly estimated; those for const1 and const3 are calculated using regression results and Equation 12.

2) Hausman tests: The equations in each set of reported regressions are estimated using Zellner's "seemingly unrelated regression" estimator (SUR).[24] This process improves the

[24] See, for example, Greene (1990), p. 510.

efficiency of the estimates by exploiting contemporaneous correlation between the error terms in different equations. If price were endogenous, Amemiya's three-stage least-squares estimator would have been used instead.[25] It exploits the between-equation correlations, eliminates simultaneity bias, and allows for sets of instruments that vary between the equations. However, Hausman specification tests were run on each of the equations, and the null hypothesis of exogenous price could not be rejected in any of them. Hence, the simpler SURE process could be used without fear of simultaneous-equations bias. The test has the following form:

H_0: Price endogenous. OLS is biased; 2SLS is consistent.

H_1: Price exogenous. OLS is consistent and efficient;[26] 2SLS is consistent but inefficient.

The asymptotic covariance matrices of the coefficient estimates, b_{OLS} and b_{2SLS}, are:

$$V[b_{2SLS}] = \sigma^2 [Z'X]^{-1} [Z'Z] [X'Z]^{-1} \tag{13}$$

$$V[b_{OLS}] = \sigma^2 [X'X]^{-1} \quad . \tag{14}$$

The specification test is then a Wald test:

$$W = (b_{OLS} - b_{2SLS})' [V_{2SLS} - V_{OLS}]^{-1} (b_{OLS} - b_{2SLS}) \quad . \tag{15}$$

The statistic W has a chi-squared distribution with K degrees of freedom, where K is the number of instruments used in the 2SLS regressions. The test is calculated using the 2SLS estimate of sigma-squared, in order to assure that the statistic is positive. The 2SLS regressions were run using housing starts, lagged housing starts, the growth rate of real GNP, and the sawtimber inventory belonging to forest-industry firms in the region as instruments (in addition to the exogenous variables in the equation).

[25] See Schmidt (1990) for a discussion of several potential 3SLS estimators, including Amemiya's.

[26] At least, it is efficient among single-equation estimators.

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