Transactions Costs and the Efficient Organization of Production: A Study of Timber-Harvesting Contracts

Keith B. Leffler

University of Washington

Randal R. Rucker

Montana State University

A transaction costs framework is developed to explain the choice between lump-sum and per unit payment provisions in private timber-harvesting contracts. Predictions about which contract type minimizes the transaction costs of presale measurement and contract enforcement and monitoring are derived and tested using private timber sales contracts from North Carolina. The empirical results provide strong support for the transaction costs approach and also reject several predictions from a risk-based model. The transaction costs framework also provides insights into the choice between negotiated and competitive sales procedures.

The work on this paper was completed while Rucker was in the Department of Economics and Business at North Carolina State University. For comments on earlier drafts, we thank Doug Allen, Lee Alston, Yoram Barzel, Gardner Brown, Carlyle Franklin, Bob Higgs, R. Glenn Hubbard, Ron Johnson, Chuck Knoeber, Jeff LaFrance, Dean Lueck, Nancy Margolis, Steve Margolis, Scott Masten, Ian Munn, Peter Nickerson, Peter Pashigian, Eric Rasmusen, V. Kerry Smith, Vince Smith, George Stigler, Wally Thurman, Doug Young, and an anonymous referee as well as participants in seminars at the University of Chicago, Clemson, North Carolina State, Montana State, Seattle, Arizona, and Simon Fraser and in the Summer 1989 National Bureau Conference on Topics in Industrial Organization. We also thank the Political Economy Research Center for financial support and Karen Carlton for secretarial support. Wade Dorsey, Myra McCrickard, Jeff Ward, and Barry Weinmann provided valuable research assistance.

[*Journal of Political Economy*, 1991, vol. 99, no. 5]
 0022-3808/91/9905-0007$01.50

Individuals and firms have incentives to develop institutions and adopt contractual arrangements that minimize the dissipation resulting from transaction costs.[1] In any particular instance, the precise nature and relative magnitude of transaction costs will be determined by the physical properties of the goods being exchanged and the characteristics of the buyers and sellers involved. As a result, institutions and contract provisions will differ across goods and with the characteristics of buyers and sellers. Detailed analyses of particular production processes, like the analysis presented in this paper, can therefore improve our understanding of the relationship between transaction costs and observed institutions and contracts. Such studies are few, presumably because of the difficulty in identifying and quantifying the relevant transaction costs of policing and enforcing input exchange agreements.

The specific production activity we study is timber harvesting. We focus on this activity because the most valued input, standing timber, is produced (in large part) naturally. This limits substantially the dimensions of the transaction costs associated with production.

In Section I we describe the nature of timber harvesting, focusing on the sources of transaction costs in that production process and on alternative means of assembling productive inputs. We conclude that transaction costs will be minimized if the timber owner transfers standing timber (rather than logs) to downstream resource owners.

In Section II we analyze the transaction costs associated with alternative contractual arrangements through which timber is purchased: lump-sum versus per unit harvested contracts. In that section we develop a transaction costs–based model that yields a variety of implications concerning the determinants of the choice of payment provisions in timber-harvesting contracts. We also compare the predictions of our transaction costs approach with those of a risk-based model. In addition, our approach provides insights into the choice between negotiated and competitive sales procedures.

In Section III we test the implications of our analysis using primary data on individual private timber-harvesting contracts in North Carolina.[2] We find broad support for the transaction costs approach. In addition, for those cases in which the risk and transaction costs ap-

[1] Cheung (1969*b*), Williamson (1971, 1979), Alchian (1977), Barzel (1987), and Allen (1991) discuss the nature of transaction costs and the distinction between costs of exchange (such as transportation) and transaction costs arising from devoting resources to exploiting (or preventing exploitation of) incomplete information about goods' attributes.

[2] Published transaction cost studies using private contract data include Cheung (1973), Umbeck (1977), Hallagan (1978), Alston and Higgs (1982), Alston, Datta, and Nugent (1984), Libecap and Wiggins (1984), Masten and Crocker (1985), Mulherin (1986), and Joskow (1987, 1988).

proaches yield different predictions, the transaction costs effects are found to dominate. In Section IV we provide concluding comments.

I. Transaction Costs in Timber Harvesting and the Efficient Organization of Inputs

Consider an individual who owns the property rights to a tract of timber and who has made the decision to sell the entire tract. To produce logs, the owner must apply to the trees labor and capital currently owned by others. Two contrasting methods of organizing these required inputs are that (1) the timber owner can hire logging resources to cut his timber and then sell logs to the mill or (2) he can sell to the mill or the logger the right to remove standing timber.[3] Because the levels of the potential transaction costs associated with these alternatives may differ greatly, the timber owner's choice of production method can have a substantial impact on the costs of producing logs. For example, if he retains the rights to the trees and hires loggers by the hour, they will have little incentive to exercise care in topping the trees or in minimizing stump heights. If, on the other hand, he sells the standing trees, the owners of the logging resources may create erosion problems and will be more reluctant to clean up messy slash. In either case, the incomplete specification and measurement of the attributes being transferred motivate each resource owner to incur (transaction) costs to measure and monitor what he buys and to exploit the incompletely measured attributes being sold. Thus the choice of who buys what from whom will significantly affect the level of transaction costs accompanying production and thus the level of output.

Although tracts of standing timber vary widely in species composition, tree quality, and density, in the short run the timber owner cannot significantly alter the value of a particular tract. In contrast, the owner of the logging resources has numerous opportunities to exploit the costliness of monitoring his behavior. For example, the value of the harvested timber is influenced by the care in felling (neighboring trees should be protected) and bucking (the log lengths should be proper) and the diligence exercised in separating logs from

[3] We are interested in the initial stage of production. Thus we abstract from the contractual arrangements among the various downstream resources and focus on differences in the relationship between the timber owner and the logging resources, whether the latter are owned by the logger, the mill, or further downstream resource owners. This issue of the degree of vertical integration in an industry (which we ignore) is one frequently analyzed in a transaction costs context (see, e.g., Coase 1937; Williamson 1971; Klein, Crawford, and Alchian 1978; Cheung 1983).

slash and in minimizing stump heights. In addition, the net value of the output to the buyer is affected by his success in limiting shirking by his employees and in enforcing the appropriate use of other logging resources.

A contract in which a timber owner transfers standing timber to the owner of logging resources ensures that the owner of the logging resources will bear the costs of differences in output value resulting from his economic actions. Such an organization of production provides an incentive for the owner of the logging resources to eliminate shirking and inefficient logging practices, thus minimizing transaction costs.[4] We expect, therefore, that transferring logging rights to standing timber will be the best way to minimize the cost of producing logs.

This expectation is supported by the empirical evidence. We collected some 200 timber contracts (see Sec. III) and interviewed over 20 forestry consultants, buyers, and sellers. In this process, we did not learn of a single tract in which the timber owner hired logging resources and sold logs to the mill.[5]

II. Costly Information and Opportunism in Timber Markets: Minimization of Transaction Costs through the Choice of Payment Method

When a timber owner sells standing timber to a mill or to an owner of logging resources, payment for these rights can be made in a variety of ways. Two payment arrangements are used typically in the timber industry: (1) a lump-sum payment in which the total payment amount is determined at the time the contract is signed or (2) a payment schedule per unit of output in which payments depend on the amount of timber harvested.[6] Previous analyses and discussions of contract choice for natural resources have emphasized the risk-sharing characteristics of lump-sum versus per unit sale contracts.[7] We, however, emphasize the difference in transaction costs.

[4] See Barzel (1987) for a discussion of these issues in a more general context.

[5] This excludes, of course, the case (which we do not consider) of vertically integrated wood-products companies, which typically mill logs from their own land and often hire logging resources to harvest their standing timber. In addition, we focus on "natural" tracts. Tree farms, in which the timber owner might be able to exercise substantial control over the characteristics of the trees, are not included in our data set.

[6] With respect to the incentives of buyers and sellers, the per unit and lump-sum payments in timber sales contracts are analogous to the royalty and bonus payments in mineral and petroleum contracts and to share and fixed-rent payments in agricultural labor contracts.

[7] See, e.g., Leland (1978) and Mead et al. (1985). For similar discussions of labor contracts, see Cheung (1969*a*), Higgs (1973), and Stiglitz (1974).

A Model of Lump-Sum Contracts[8]

Consider a lump-sum contract in which a tract of standing timber is sold to the high bidder.[9] We assume that bidders are homogeneous: if all the attributes of the tract are known, all bidders will place the same value (v) on the tract. Also, they all employ the same bidding strategy and have the same "uninformed" prior distribution function, $G(v)$, with expected value μ_0 and variance σ^2. All bidders are risk neutral and are profit maximizers. They also correctly estimate how many offers, N, will be made for the resource.

The risk-neutral seller (or his agent) provides public information about the sale, and this information is used by bidders in formulating $G(v)$. Each bidder then is able to collect further private information through presale measurement at a cost of M. This presale measurement occurs through a timber cruise in which a sample is taken of species and product composition, count, size, and condition of the trees on the tract.

Individual private information results in a sample value estimate for bidder j of i_j. Each individual's measurement sample is drawn independently from the same distribution $F(i|v)$. Bidder j combines the prior, $G(v)$, with his sample information, i_j, to form a modified estimate of the expected value of the resource, μ_{1j}, based on the presumption that i_j is the highest-valued information sample.[10] The bid then made by bidder j, B_j, is less than μ_{1j} (by an amount ΔX_j) because competitors by assumption are expected to have lower (modified) estimates of the tract value.[11]

A zero-profit equilibrium is obtained by allowing the number of bidders in the auction to be endogenous. The expected payoff to a prospective bidder from bidding is

$$\frac{\Delta X}{N} = \frac{E[\mu_1 - B(N)]}{N} = \frac{v - E[B(N)]}{N}, \tag{1}$$

where ΔX is the expected return to the winning bidder over a large number of (identical) tracts, E is the expectation operator, and $E[B(N)]$ is the expected winning bid in a sale with N bidders. On average (over a large number of tracts), the modified estimate (after

[8] The auction framework developed below for lump-sum sales is a "common-values," sealed-bid auction model adapted from French and McCormick (1984). Their model is, in turn, an adaptation of models by Wilson (1977), Johnson (1979), and Ramsey (1985).

[9] Because private timber sale contracts are usually fairly short-term (24 months or less), we abstract from any temporal aspects of these contracts.

[10] That is, the winner's curse is taken into account (see Wilson 1977; French and McCormick 1984). Note that for all but the winning bidder, μ_{1j} is a biased estimate of the true value of the tract (v).

[11] See French and McCormick for elaboration of this point.

private measurement) of the expected value of the resource held by the high bidder (μ_1) will equal the true value of the tract; that is, $E(\mu_1) = v$. New bidders will enter until the expected payoff from bidding ($\Delta X/N$) is equal to the expected cost of presale measurement, M, that is, until each bidder's expected profits are zero, or $E(\pi_b) = (\{v - E[B(N)]\}/N) - M = (\Delta X/N) - M = 0$.[12] This equilibrium condition can be written as

$$E[B(N^*)] \equiv B^* \equiv v - M \cdot N^*, \tag{1'}$$

where N^* and B^* are the number of bidders and the bid (the seller's revenue) in equilibrium.

In the equilibrium described by equation (1′), it is apparent that the resource owner "pays" all measurement costs, in the sense that increases in $M \cdot N^*$ reduce B^* on a dollar-for-dollar basis. This result is reasonable in our context of landowners that hold relatively small tracts and have very inelastic supplies of standing timber. Even in a broader context, where economywide changes in M would induce changes in v (through changes in log prices) and thereby in B^*, equation (1′) captures the incentives of the individual timber owner. Any innovative activity in contracting by the individual timber owner that reduces M will yield a corresponding increase in the equilibrium bid for the tract.

As suggested by Barzel (1982) in a more general context, the individual seller therefore has an incentive to influence buyers' measurement activity. The seller would prohibit presale measurement completely if he could do so without incurring any costs, that is, if this prohibition did not reduce the number of bidders or alter the bidders' beliefs concerning the tract's value. More realistically, the seller will have incentives to reduce M, thereby lowering total presale measurement costs ($M \cdot N^*$) and increasing his revenues (B^*).[13] He might accomplish this by, for example, cutting roads into the stand, providing aerial photos, supplying detailed area-specific cruises, hiring reputable third parties to provide tract information, and so forth.

There are also contractual means of reducing buyers' presale measurement incentives. If purchaser payment is made contingent on the volume and quality of logs removed from the tract, the purchaser

[12] The number of bidders will be finite given that the expected payoff, $\Delta X/N$, decreases as the number of bidders increases. This occurs for two reasons: first, the probability that a particular bidder will win the auction decreases as the number of bidders increases, and second, bidders will decrease the adjustment to their postmeasurement estimate of value, ΔX, as the number of bidders increases (see French and McCormick [1984, p. 423] for elaboration).

[13] A decrease in M induces a less than proportional increase in N^*. The reason is that ΔX (which in equilibrium equals $M \cdot N^*$) decreases as N increases. Total measurement costs therefore decrease and seller's revenue increases.

will have less incentive to measure the timber before the sale. A landowner may therefore be able to limit dissipation due to presale measurement and increase his net returns by using a contingent-payment contract. We now turn to a discussion of such contracts as a means of reducing presale measurement.

A Model of Per Unit Contracts

Under a per unit harvested contract, the total payment made by the buyer is determined by the actual volume and composition of timber harvested. This type of contract greatly reduces a prospective buyer's incentives for presale measurement because such measurement gives him no useful information to exploit. In fact, buyers and timber consultants have told us that buyers frequently do not bother to conduct presale cruises of per unit sales. For simplicity, we therefore assume that no presale measurement takes place for per unit sales. Thus if presale measurement were the only source of transaction costs, we would expect all resource sales to be conducted on a per unit basis. But other transaction costs must also be considered. In particular, payment method will influence the buyer's incentive to harvest the tract efficiently.

In figure 1, let P be the per unit value of the logs obtained from a particular tract of standing timber.[14] The line MC_H, the expected marginal cost of harvest (or of transforming standing timber into logs), slopes upward because, for example, some of the standing timber is further from the logging road or is on terrain that is more difficult to log.[15] The right to harvest the timber is granted to the bidder offering the highest per unit payment, R.[16] Because the net

[14] The per unit contracts we model are "ideal" in the sense that we assume that they specify a per unit payment for each grade and species of timber on the tract. For simplicity, the discussion presumes a tract with one species and one grade of timber.

[15] We assume that harvest by a single buyer is efficient. This will be the case if marginal costs of harvest increase because of tract characteristics or there are significant fixed costs of harvesting a timber tract.

[16] We constrain the per unit bid not to vary with harvested quantity (this constraint conforms with our observation that harvest-dependent per unit payments are not used in practice). We can identify two reasons for not specifying reduced per unit payments with increased harvest as a means of increasing a buyer's preferred level of harvest. First, in per unit contracts, different payments are typically offered for different grades and species of timber. If each per unit payment varied with measured harvest, the cost of formulating and assessing bids likely would increase substantially. Second, buyers would have greater incentives to cheat on reported species type and grade. For example, if the high-volume payment for a more expensive species falls below the low-volume payment for a less expensive species (given the large number of potential species-grade combinations, this is likely), a buyer with a tract that turns out to have an unexpectedly low volume of low-value timber might attempt to reduce his payments by reporting the low-value grades as high-value grades. Obviously, sellers' costs of monitoring harvest levels could increase significantly.

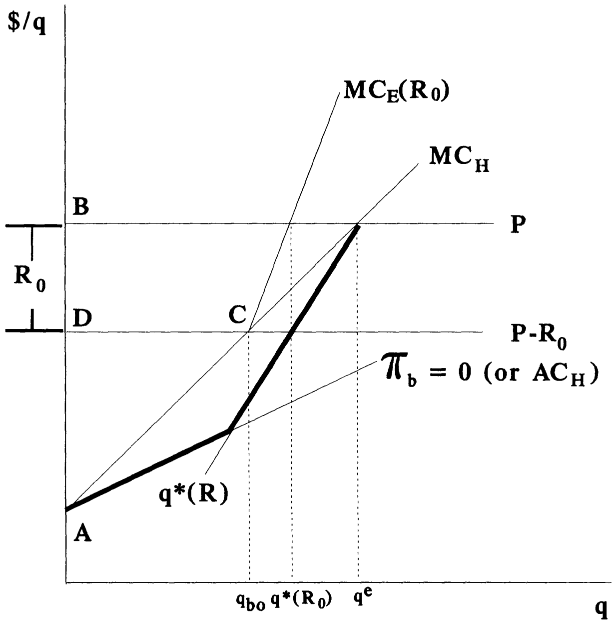

FIG. 1.—Per unit payment contracts: buyer's and seller's profit-maximizing harvest levels for given per unit bids.

value of additional harvest to the buyer is now $P - R$, the per unit contract affects the harvesting incentives of the buyer. For example, the buyer's profit-maximizing harvest with an initial per unit payment of R_0 in figure 1 is q_{b0}, which is less than the harvest level that would maximize the joint profits of the buyer and the timber owner, q^e.[17] This contrasts with a lump-sum sale, in which the buyer harvests q^e, where MC_H equals P.[18]

The seller can control the harvest incentive problem created with a per unit payment by specifying and enforcing the level of harvest.[19]

[17] Note that with a per unit bid of R_0 and a harvest level of q_{b0}, the buyer's quasi rent is area ADC. In fact, for all bids less than $R = AB$ (the difference between P and the marginal cost intercept), a buyer choosing the level of harvest makes positive rent. Hence, without minimum harvest levels, competition implies a bid of AB and the incentive not to harvest. This adds to the speculative incentives to default on timber contracts discussed at length by Rucker and Leffler (1988).

[18] Some monitoring of the buyer's activities on a lump-sum contract may nonetheless be required. The reason is that the landowner wants to prevent the buyer from engaging in activities that reduce the value of his resource in other current uses (e.g., farming on land bordering roads used to access the timber tract) or in future uses (either timber or nontimber). These monitoring costs are present under both payment schemes.

[19] The specification of "harvest levels" is common in contracts for natural resources. For example, oil leases often specify minimum flow requirements, and timber contracts require that all timber larger than a specified diameter be harvested. In agricultural labor contracts the labor input of share tenants may be specified (Cheung 1969*a*).

Assume that the timber owner can enforce a chosen harvest level, q, but that enforcement is costly.[20] For any per unit payment, R, there will be a corresponding profit-maximizing harvest level for the buyer, $q_b = q_b(R)$. The timber owner will be able to induce the buyer to harvest more than q_b only by expending resources. Presumably, the greater the divergence between q and q_b, the greater the enforcement costs, C_E. Let $C_E = C_E[q - q_b(R)] + F_E$ be the landowner's enforcement cost function, where q is the actual enforced harvest level and F_E is the fixed cost associated with the volume-monitoring system. Assume also that $\partial C_E/\partial q > 0$ and $\partial^2 C_E/\partial q^2 > 0$, for all $q > q_b(R)$.

Figure 1 illustrates the landowner's constraints. For a given per unit bid, say R_0, enforcement begins at the buyer's preferred harvest level q_{b0}, where $P - R_0$ (net value to the buyer) intersects the marginal harvesting cost (MC_H). The seller's desired level of harvest is $q^*(R_0)$, the harvest level at which the marginal cost of enforcement, $MC_E(R_0)$, equals the marginal benefits of enforcement to the landowner, R_0. The line labeled $q^*(R)$ shows the locus of seller-chosen harvest levels as a function of the net harvest value to the purchaser (the per unit stumpage value, P, less the bid, R).

The seller is constrained to specify per unit payment–harvest combinations that result in nonnegative buyer profits. This constraint is shown in figure 1 by the average cost of harvest, which we label $\pi_b = 0$; areas above $\pi_b = 0$ are regions of positive profit for the bidders.[21] The seller is therefore limited in his choice of combinations of R and q to points on or above $\pi_b = 0$, implying that the profit-maximizing combinations are restricted to points on the heavily shaded line segments in figure 1.

As indicated by the preceding discussion, the landowner's problem is to choose a per unit payment R and a harvest level q to

$$\max_{q,R} \pi_L = R \cdot q - C_E[q - q_b(R)] - F_E \qquad (2)$$
$$\text{subject to } \pi_b = (P - R)q - C_H(q) \geq 0,$$

where π_L is the landowner's profit, π_b is the buyer's profit, and $C_H(q)$ is the total harvest cost.

[20] The ensuing discussion is a description of the ex ante equilibrium harvest level. Our characterization of ex post behavior is that the harvest level actually enforced will vary with the revealed volume of logs on the tract. If the actual volume is small (large), the marginal cost of harvest will be high (low) and the enforced harvest level will be low (high). This characterization is consistent with actual contracts that normally specify harvest levels in terms of "merchantable" timber or minimum diameters rather than in absolute levels of harvest.

[21] Figure 1 illustrates a case with zero fixed costs of harvest. No substantive changes result from incorporating positive fixed costs and the resulting U-shaped average cost.

The Kuhn-Tucker conditions for a maximum in (2) are

$$\frac{\partial \mathcal{L}}{\partial q} = R - MC_E + \lambda[MC_H - (P - R)] = 0, \tag{3}$$

$$\frac{\partial \mathcal{L}}{\partial R} = q - \frac{\partial C_E}{\partial q_b} \cdot \frac{\partial q_b}{\partial R} + \lambda \cdot q = 0, \tag{4}$$

$$\frac{\partial \mathcal{L}}{\partial \lambda} = (P - R)q - C_H(q) \geq 0; \quad \text{if} > 0, \text{then } \lambda = 0. \tag{5}$$

To interpret these conditions, suppose initially that the bidder's zero-profit constraint is not binding, that is, that $\lambda = 0$ and $\pi_b > 0$. In this case, expression (4) indicates that the landowner will increase the per unit payment (R) until marginal benefits and marginal costs are equal. For a given harvest level, the marginal benefit from a \$1.00 increase in R is the level of harvest (q). The marginal cost is the increased enforcement cost resulting because an increase in the per unit bid reduces the buyer's preferred harvest level. If the bidder's zero-profit constraint is binding, then $\pi_b = 0$, $\lambda < 0$, and expressions (3) and (4) each have an additional negative term, $\lambda[MC_H - (P - R)]$ and $\lambda \cdot q$. These terms represent the profit the seller must give up to the buyer if the seller increases harvest or per unit payments when the buyer's zero-profit constraint is binding.[22]

A striking result of this analysis is the possibility that the landowner's profits may be maximized at a bid-harvest combination in which the buyer's zero-profit constraint is not binding; that is, the seller's maximum profits may occur at bid-harvest levels implying positive buyer profits.[23] In such a situation, the benefits to the landowner of a higher per unit payment will be outweighed by the higher costs of enforcing any given level of harvest that result because the higher payment reduces the buyer's desired harvest. Models that assume that the constraint on buyer profits is binding (such as those developed in other contexts by Cheung [1968], Stiglitz [1974], and

[22] The per unit payment-harvest combination that maximizes the seller's profit is not seen trivially in fig. 1. In an unpublished appendix (available from the authors), we describe both graphically and algebraically the solution to the seller's problem for linear marginal harvest and enforcement costs. We also derive and discuss the conditions under which the buyer's profit constraint is binding. The result is that the buyer's zero-profit constraint is not binding if the costs of enforcement are high relative to the costs of harvest. Intuitively, when enforcement is cheap, it pays the landowner to enforce a harvest level that extracts all the buyer's profits.

[23] Of course, we expect buyers' profits to be competed away as they expend resources to become preferred negotiating buyers. Thus we might predict relatively larger "entertainment" expenses by private timber buyers, efforts to be the first buyer to knock on a prospective seller's door, or agreement by buyers to incur "extra" expenses building roads or cleaning up slash.

Leland [1978]) preclude this outcome. The possibility that it may be in the interest of both risk-neutral resource owners and prospective buyers to agree on lower per unit payments than would be offered under unrestricted competition simply is not allowed.

Landowners can restrict competition by negotiating the sale of their timber with a single (or limited number of) buyer(s) or by considering only invited bids. Restrictions on competition have no similar benefits in our model of a lump-sum contract, where limiting the number of bidders simply reduces the seller's revenues. We therefore predict greater reliance on negotiated sales for per unit contracts than for lump-sum contracts.

Figure 2 shows an enforcement cost equilibrium for a nonbinding buyer zero-profit constraint. The profit-maximizing bid-harvest combination is R^*, q^*, with the seller's total revenue equal to $R^* \cdot q^*$. Part of this revenue is dissipated in enforcing the contracted quantity, as shown by the vertically shaded enforcement costs, E^*. Of the potential value of the timber (ABC), a portion also is dissipated by a buyer's shirking in harvesting (shown by the diagonally shaded area, S^*).[24] The seller also bears the fixed costs associated with monitoring harvest levels, F_E. The seller's profit, π_L^*, is thus the potential value of the timber as logs minus the total transaction costs, $E^* + S^* + F_E$, minus the buyer's profit ($\pi_b^* = \pi_b^+ - \pi_b^-$).[25]

The Choice between Lump-Sum and Per Unit Contracts

For either a lump-sum or a per unit contract, the net value to the landowner of a tract of timber is the potential value of the tract minus the costs associated with presale measurement and enforcement. The resource owner will choose the payment provision that maximizes his expected net return. Of course, it would be possible for the seller to use a mixed contract that combines a lump-sum payment with contingent per unit payments. In our investigation of timber-harvesting contracts, however, we have not learned of a single instance of such a mixed contract. Significant fixed costs for each of the relevant transaction costs—presale measurement and enforcement—can explain the dominance of the pure contract types.

Given a choice between a pure lump-sum or a pure per unit contract, the seller's profit-maximizing decision is determined by whether the transaction costs from a lump-sum contract ($M \cdot N^*$) are less than or greater than those from a per unit contract ($E^* + S^* + F_E$) plus

[24] Of course, enforcement costs are incurred because of shirking. Although one might label $E^* + S^*$ shirking costs, we find it useful to distinguish the direct cost expended, E^*, from the value never produced, S^*.

[25] Figure 2 is drawn for the case in which F_E is zero.

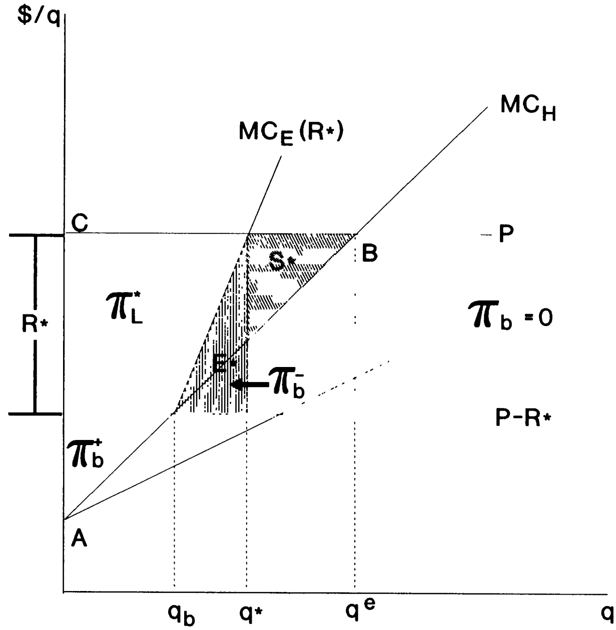

FIG. 2.—Equilibrium per unit contracts with nonbinding buyer zero-profit constraint. Seller's profits = π_L^*, buyer's profits = $\pi_b^* = \pi_b^+ - \pi_b^-$, enforcement costs = E^*, and shirking costs = S^*.

any buyer's profit. Although we cannot specify a priori when $M \cdot N^*$ will be greater or less than $E^* + S^* + F_E + \pi_b^*$, we can identify observable variables that have independent effects on the transaction costs of lump-sum sales ($M \cdot N^*$) or per unit sales ($E^* + S^* + F_E$) and also on the buyer's profit from per unit sales. Thus we can predict the conditions under which contracts with per unit payment provisions are more or less likely to be chosen than lump-sum contracts. These predictions result from identifying factors that change (1) the costs to prospective buyers of presale measurement and (2) the costs to landowners of enforcing specified harvest levels on per unit contracts. Factors affecting these costs include the physical characteristics of the tract and characteristics of both buyers and sellers.

Predictions Concerning the Choice of Payment Provisions

Consider first the factors affecting presale measurement costs. Presale measurement provides a sample of information concerning the actual value (quantity and quality) of timber on the tract. This information is obtained at a cost. Our discussion above suggests that, ceteris paribus, the lower the presale measurement costs per buyer (M), the lower the transaction costs associated with a lump-sum contract.

The individual buyer's incentive to measure is based on the likelihood that he will gain information superior to that of the competing bidders. If the information obtained from measurement indicates that the tract is unusually valuable, then he may be able to obtain the tract at a price below its value. If measurement shows the tract to be of unexpectedly low value, he avoids a loss. An important feature of the prospective bidders' incentives to measure is that the greater the variance of the value of the tract, the more valuable private information will be. Therefore, we expect that M and also $M \cdot N^*$ (total measurement costs) will be greater for tracts with greater variance. Thus our first prediction is that the more heterogeneous (i.e., the more variable) the tract, the more likely a per unit timber contract. Similarly, the less reliable the seller's presale information, the more likely a per unit contract.

The dissipation due to excessive presale measurement ($N^* \cdot M$) will increase not only when buyers' incentives to measure increase (because the variance of the premeasurement tract value is larger) but also when the fixed costs associated with presale measurement increase.[26] Thus we predict that when buyer measurement is more expensive, per unit contracts are more likely.[27] In addition, when the cost of measurement is prohibitive (because of high fixed costs of presale measurement), buyers will be unwilling to purchase timber on a lump-sum basis and per unit contracts will prevail.[28]

An additional prediction results from differences in enforcement costs on lump-sum and per unit contracts. Where the seller's cost of monitoring buyer-harvesting activity is low, the transaction costs of per unit contracts (and the buyer's profit, if any) are low and per unit contracts are more likely.

The reigning alternative to the transaction costs explanation for

[26] We limit this statement (and the associated predictions) to changes in the fixed costs associated with presale measurement. The direction of the effect on M of a change in the marginal costs of presale measurement is determined by the elasticity of the marginal benefit curve for presale measurement, a value on which we have no information.

[27] In our model, presale buyer measurement does not alter the value of the tract; hence it is never efficient. If, however, buyers use timber for very different purposes and if the specific characteristics valued by buyers are "taste attributes," presale buyer measurement is nonduplicative and likely efficient. Hence for very unusual tracts with rare species, we expect efficient buyer presale measurement and an increased likelihood of lump-sum contracts.

[28] If buyers do not undertake presale measurement on a lump-sum contract, a "lemons" phenomenon (Akerlof 1970) is likely to result. A solution to such a problem in the present context is to use per unit payment contracts.

contract choice is risk aversion. The presale measurement associated with a lump-sum contract acts to reduce the total risk shared by the buyer and seller as compared to the total risk shared under a per unit contract.[29] Given risk aversion, the greater the riskiness (variability or heterogeneity) of a tract, the more valuable the risk reduction of the presale measurement. Thus the more heterogeneous a tract, the less likely a per unit contract.[30] This prediction contradicts that of the transaction costs model, implying that we may be able to determine empirically whether transaction costs or risk is the more important factor in this aspect of contract choice.

III. Empirical Tests of the Transaction Cost Theory of Contract Choice

The analysis of Section II yields predictions that per unit contracts are more likely when (*A*) presale measurement costs are higher as a result of (1) more heterogeneous tracts, (2) less reliable seller-provided presale information, and (3) more expensive buyers' presale measurement and (*B*) monitoring of harvesting activities is relatively cheap. To test these hypotheses, we collected data on private timber-harvesting contracts by interviewing timber buyers, sellers, and forestry consultants throughout North Carolina.[31] We obtained information on empirical proxies for the variables suggested by the theory of Section II for 188 usable timber-harvesting contracts from recent years.[32] Sample sizes from individual interviewees ranged from three to 27 sales, depending on the patience of the source. A description of these empirical proxies and of their predicted effects follows. Table 1 displays the variable names, variable definitions, predicted effects, and sample statistics for these proxies. Table 2 presents a correlation matrix.

[29] Under a lump-sum contract, the seller still bears some risk because prior to the sale, there is uncertainty concerning the level of the high bid.

[30] Leland (1978) formally derives an analogous prediction in a model with a risk-averse resource owner selling to competing risk-averse buyers, but with no explicit treatment of presale measurement.

[31] North Carolina is a major timber-growing state, with over 90 percent of both the inventory of standing timber and timberland area being privately owned. In 1984, more than 400 million cubic feet of timber with a value of $241 million was harvested from private land in North Carolina, with timber ranking second in value only to tobacco among the state's agricultural crops (U.S. Department of Agriculture 1988). Only 23 percent of the timberland in the South is owned by the forest industry. Ten percent is publicly owned. The remaining 67 percent is owned by individuals and companies not in the business of growing trees. We focus on this latter group of owners.

[32] As we indicate below, the size of the sample of usable contracts depends on the empirical specification chosen for testing the model.

TABLE 1

VARIABLE DEFINITIONS, PREDICTED EFFECTS, AND SAMPLE STATISTICS (153 Observations)

		Effect						
Variable	Definition	Presale Measurement	Enforcement	Predicted Sign	Mean	Minimum	Maximum	Standard Deviation
PERUNIT	Payment provision (0 = lump-sum, 1 = per unit)				PERUNIT = 1; 31 observations			
%PINE*	Percentage pine sawtimber (omitted from regressions)				43.59	0	100	26.33
%HARDWOOD	Percentage hardwood sawtimber	+		+	18.64	0	98.3	23.37
%PULP	Percentage pulpwood	−	+	?	33.52	0	100	26.87
%C&SAW	Percentage pine chip-and-saw	−	+	?	4.25	0	56.4	8.34
VOLUME	Volume of timber on the tract	+	−	?	581.3	1.43	4,111.1	649

LOWVAR	Low-variance timber tract (1 = low-variance, 0 = not low-variance)	+		+	LOWVAR = 1; 15 observations			
NSPECIES	Number of species (1–18 integer valued)	–		–	6.84	1	18	3.34
CONSULT	Consultant involved in sale (0 = no consultant, 1 = consultant)	–	+	?	CONSULT = 1; 139 observations			
NIPF	Nonindustrial private forest owner (0 = large owner, 1 = small [NIPF] owner)	+	–	?	NIPF = 1; 141 observations			
ACCESS	Access conditions (0–4 integer variable, 0 = poor)	–		–	2.29	0	4	1.44
BUYSIZE	Buyer size (0 = small, 1 = medium, 2 = large)	–		–	1.16	0	2	.82
THIN	Thinning sale (0 = harvest, 1 = thinning)		+	+	THIN = 1; 24 observations			
VALUE	Tract value ($1,000's)		–	–	54.14	0	393	67.60

* This variable is the tract composition variable that is omitted from the regressions

TABLE 2

CORRELATION MATRIX (153 Observations)

	PERUNIT	%HARDWOOD	%PULP	%C&SAW	VOLUME	LOWVAR	NSPECIES	CONSULT	NIPF	ACCESS	BUYSIZE	THIN	VALUE
PERUNIT	1.000												
%HARDWOOD	−.167	1.000											
%PULP	.433	−.404	1.000										
%C&SAW	.064	−.295	−.049	1.000									
VOLUME	−.122	−.043	−.054	.087	1.000								
LOWVAR	.490	−.210	.654	−.007	−.234	1.000							
NSPECIES	−.303	.580	−.205	−.196	.261	.281	1.000						
CONSULT	−.122	.182	−.293	.005	−.087	−.124	.189	1.000					
NIPF	−.034	−.113	−.025	.121	−.251	−.067	−.058	−.008	1.000				
ACCESS	.058	−.099	.032	−.054	−.084	.072	−.116	.048	−.060	1.000			
BUYSIZE	−.276	−.128	−.027	.028	.268	−.198	.029	−.133	−.063	.006	1.000		
THIN	.498	.025	.178	−.053	−.137	.341	−.103	.012	−.008	.189	−.259	1.000	
VALUE	−.204	−.113	−.164	.125	.901	−.235	.141	−.054	−.157	−.061	.293	−.200	1.000

Variable Descriptions

A. Presale Measurement Cost Variables

1. *Tract heterogeneity variables.*—Tract heterogeneity is determined by such factors as the composition and volume of the timber on the tract. North Carolina forests contain hardwood sawtimber, which is quite variable in value; pine sawtimber, which is more uniform in value; and pine chip-and-saw and pulpwood timber, which is homogeneous in value. The tract composition variables used in our empirical analysis are the following:

$\%HARDWOOD_i$: The percentage of hardwood sawtimber on tract i. An increase in %HARDWOOD (offset by an equal reduction in the tract composition variable omitted from the regressions, the percentage of pine sawtimber, %PINE) is predicted to increase the likelihood of per unit contracts.

$\%PULP_i$ and $\%C\&SAW_i$: The percentage of pulpwood and pine chip-and-saw on tract i. This heterogeneity effect predicts that an increase in either %PULP or %C&SAW (again offset by a reduction in %PINE) will reduce the likelihood of per unit contracts.

Two other variables also measure differences in tract heterogeneity:

$VOLUME_i$: The volume of timber on tract i. With composition held constant, an increase in volume increases the variance of a tract's value,[33] thereby increasing presale measurement expenditures. This heterogeneity effect therefore predicts that an increase in VOLUME will increase the likelihood of per unit contracts.

$LOWVAR_i$: A dummy variable assigned a value of one on the 10 percent of the sales in our sample with the lowest variance.[34] The

[33] To see that an increase in volume increases variance, consider a tract with one tree that, because of its perceived size and quality (according to the seller-provided information), has an expected value of $110, and prospective buyers' perceptions are that the actual value of the tract is either $100 or $120, both with a probability of .5. Now suppose that the number of trees on the tract doubles to two. If the expectations concerning the second tree are identical to those of the first (i.e., with composition held constant), the tract now has an expected value of $220 with potential realized values of $200 with probability .25, $220 with probability .50, and $240 with probability .25. The variance of the tract thus increases from 100 to 200 with the increase in volume.

[34] In our data set, we identify low-variance tracts as those with a low proportion of sawtimber and a low volume. Because there is no way to know precisely how changes in these two factors affect tract variance, we test for sensitivity of our empirical results to different definitions of the low-variance tracts in our sample. The estimated coefficients on the other variables in our model are not sensitive to these modifications, and, in general, the estimated coefficient on LOWVAR is not affected either. The exception to this is that (as would be expected) the significance of the estimated coefficient on LOWVAR diminishes as its definition is changed to include higher-variance tracts.

ex ante variance in the value of a tract will determine whether presale measurement is worthwhile. For low-variance tracts, the fixed costs of cruising (transporting material and personnel to the tract) will likely outweigh the benefits, implying that buyers will choose to undertake no presale measurement (cruise). Assuming that buyers will not enter into a lump-sum contract without cruising the tract,[35] we predict a higher likelihood of per unit contracts on low-variance tracts.

2. *Seller-provided presale information variables.*— Factors such as the detail and specificity of seller-provided presale information will also determine the presale variance of a tract's value. Variables included to measure this effect are the following:

NSPECIES_i: An integer variable for the number of species identified in the seller's presale cruise information. The more species identified, the more detailed (and therefore more reliable) the seller's cruise.[36] As NSPECIES increases, we predict per unit contracts to be less likely.

CONSULT_i: A dummy variable assigned a value of one if the seller hired an independent forestry consultant to provide presale information and to conduct the sale. This effect predicts that the use of a consultant (with his experience and reputational capital behind his cruise) will increase the reliability of a seller's presale information, thus decreasing the likelihood of per unit contracts.

NIPF_i: A dummy variable assigned a value of one if the timber seller is a nonindustrial private forest (small) landowner. Small landowners with little experience in the timber market will likely provide poorer-quality presale information. This effect therefore predicts a higher likelihood of per unit contracts on NIPF tracts.

3. *Buyer presale measurement variables.*—We have also argued that higher buyer presale measurement costs will encourage use of per unit contracts. Possible empirical proxies for buyers' measurement costs include weather conditions, tract locations, tract access, and the buyer's size and experience. Of these, we were able to construct the following two variables:

ACCESS_i: An integer variable measuring the access conditions to a tract. Interviewees rated the accessibility of each tract on a scale of

[35] This assumption is consistent with comments made by a number of the individuals we interviewed that they would not purchase certain tracts on a lump-sum basis because the tracts were not worth the time and effort required to cruise them.

[36] The types of trees on the various tracts in our sample are generally the same. The tracts have loblolly pine, Virginia pine, white pine, and a variety of hardwood species: white oak, poplar, maple, walnut, sweet gum, red oak, and ash. Some seller cruises distinguish, e.g., the different types of pine; others do not. Some cruises count only the major species on the tract; others count them all.

zero to four, with zero indicating poor and four indicating excellent access. As access to the tract improves (ACCESS increases), buyers' presale measurement costs fall and per unit sales become less likely.

BUYSIZE_i: An integer variable measuring the buyer's size and experience. Each buyer is included in one of three size categories (small = 0, medium = 1, or large = 2). Larger buyers will be more experienced at presale measurement and will cruise more tracts at a lower average cost. Thus we predict that the larger the buyer, the lower the likelihood of per unit sales.

B. Enforcement/Monitoring Cost Variables

Per unit contracts will be relatively cheaper and will be chosen more often when the seller has substantial incentives to monitor the harvest regardless of the contract used. The variable we use to measure this effect follows:

THIN_i: A dummy variable assigned a value of one for thinning sales and zero for harvest (clear-cut) sales. Because the postharvest timber value on a thinning sale can be substantially affected if the wrong trees are harvested, contract-independent monitoring incentives will exist for thinning sales. We therefore predict a greater likelihood of per unit contracts on thinning sales.

Other enforcement cost predictions are related to the seller's costs under a per unit contract of monitoring the quantity of timber removed from a tract. The cost of such monitoring depends on the composition of the tract. Pulpwood is simply weighed, while sawtimber (both hardwood and pine) is typically stick-scaled, a procedure that involves measuring the length and the diameter of the small end of each log and converting these measurements to the specified payment units (thousands of board feet). To monitor harvest levels on a per unit contract, the landowner must therefore understand the appropriate scaling procedure (or procedures) and also monitor the volume of logs harvested.[37] We include three variables to measure these effects:

$\%\text{PULP}_i$ and $\%\text{C\&SAW}_i$: Defined above. The costs of monitoring harvest will fall as the proportion of sawtimber falls (%PULP or %C&SAW increases).[38] This effect predicts, therefore, that an in-

[37] The costs incurred by the landowner to understand the appropriate scaling procedure (which do not vary with the level of enforcement effort) are the empirical counterpart of the fixed costs of enforcement (F_E) mentioned in Sec. II.

[38] The reason is that landowners will have an incentive to observe the sizes and count the number of logs on trucks with sawlogs rather than simply count the number of trucks with pulpwood.

crease in either %PULP or %C&SAW on a tract will increase the likelihood of a per unit contract.

VOLUME_i: Defined above. With tract composition held constant, an increase in volume increases the truckloads of logs the timber owner observes and counts, thereby increasing harvest-monitoring costs and reducing the likelihood of per unit contracts.

Because the predicted effects for these three variables are opposite of the heterogeneity-related predictions discussed earlier, we have no predictions for them. A change in tract composition between pine and hardwood sawtimber, however, does not entail any change in harvest-monitoring costs, so that our analysis does provide a prediction for %HARDWOOD.

Three other variables also measure the seller's monitoring costs:

VALUE_i: The market value of the timber on tract *i*. With volume and tract composition held constant, an increase in a tract's value resulting from an increase in the per unit log value (P) leads to an increase in the optimal per unit payment (R^*); this increases the dissipation associated with a per unit contract, thereby decreasing the likelihood of a per unit contract.[39]

CONSULT_i: Defined above. Consultants will have more experience monitoring harvesting behavior, thus reducing the cost of enforcement. This effect therefore predicts a greater likelihood of per unit contracts on sales involving a consultant.

NIPF_i: Defined above. Small (NIPF) landowners will be less proficient at monitoring harvesting behavior than larger (more experienced) landowners. This effect therefore predicts a lower likelihood of per unit contracts on NIPF sales.

Because the enforcement cost effects for CONSULT and NIPF act in the opposite direction of the presale measurement cost effects discussed earlier, our analysis provides no prediction for their empirical effects.

Empirical Results

Our data set includes information on 188 tracts for most of the variables discussed above. We could not, however, obtain value estimates for 35 of these tracts. Table 3 presents coefficient estimates from

[39] This result can be seen as follows. In expression (1), an increase in the per unit value of the timber (with volume and composition held constant) will increase v and $E[B(N)]$ by equal amounts; it will have no effect on the costs associated with a lump-sum contract. In our unpublished appendix, we show that an increase in the per unit price (P) increases the optimal per unit payment (R^*). Thus, in fig. 2, an increase in P increases the per unit payment and therefore the size of the triangles representing dissipation on the per unit contract.

three logit regressions explaining the choice of payment provision. The likelihood ratio tests in all cases reject the null hypothesis that the variable coefficients are jointly equal to zero. Regression 1 includes all the variables discussed for the 153 observations with complete data. The regression results support every prediction of the transaction costs model. In all cases the estimated coefficient has the predicted sign and is significant at the 11 percent level or less.[40]

Regressions 2 and 3 allow evaluation of the full data set. In regression 2, we exclude the value variable and estimate the model using all 188 contracts. Regression 3 has the same specification as regression 2 but uses only the 153 contracts used in regression 1. Generally, the results for the variables with a priori predictions are unchanged.

The regression results reported in table 3 demonstrate the robustness of our empirical results and provide strong support for our transaction costs theory of contract choice. We now compare the predictions from our model with those from a risk-based model.

A Comparison of Transaction Costs and Risk-based Predictions

As discussed above, a lump-sum contract leads to presale measurement, which reduces the total risk shared by the buyer and seller. A risk-based model therefore predicts that the more heterogeneous a tract, the less likely a per unit contract.[41] Thus risk-based predictions on the tract composition variables are that an increase in %PULP or %C&SAW will increase the likelihood of per unit contracts and that an increase in %HARDWOOD will decrease the use of per unit contracts. Similarly, a risk-based analysis predicts that an increase in NSPECIES (which indicates an increase in the quality of seller-provided information) will increase the likelihood of per unit contracts and that an increase in VOLUME (which increases tract variance) will reduce the likelihood of a per unit contract.

From the estimated coefficients in regression 1 of table 3, the positive estimated coefficients on %PULP and %C&SAW support a risk-based model (though they are not inconsistent with the transaction costs model). The positive coefficient on %HARDWOOD and the negative coefficient on NSPECIES are, however, contrary to the pre-

[40] There are considerable differences in the geographical characteristics and market conditions in different regions of North Carolina. To correct for potential bias from the omission of such factors, we included dummy variables for five different regions in North Carolina. These variables were not significant, and their inclusion had little effect on the other estimated coefficients. Also, omitting the insignificant variables CONSULT and NIPF did not affect either the estimated coefficients on the other variables or the fit of the model.

[41] The risk-based predictions discussed are consistent with the predictions from the model developed by Leland (1978).

TABLE 3

REGRESSIONS EXPLAINING THE CHOICE BETWEEN LUMP-SUM AND PER UNIT TIMBER-HARVESTING CONTRACTS

EXPLANATORY VARIABLE	PREDICTIONS: Transaction Costs Model	PREDICTIONS: Risk Model	REGRESSIONS: 1 (N = 153)	REGRESSIONS: 2 (N = 188)	REGRESSIONS: 3 (N = 153)
Constant			.11 (.06)	−.39 (−.27)	−.77 (−.40)
%HARDWOOD	+	−	.04 (1.59) [.06][1]	.04 (2.53) [.01][1]	.04 (1.99) [.02][1]
%PULP	?	+	.04 (2.05) [.04][2]	.06 (3.55) [.00][2]	.06 (2.91) [.00][2]
%C&SAW	?	+	.08 (1.77) [.08][2]	.06 (1.61) [.11][2]	.07 (1.68) [.09][2]
VOLUME	?	−	.003 (2.00) [.05][2]	.001 (1.68) [.09][2]	.001 (1.29) [.20][2]
LOWVAR	+		1.97 (1.50) [.07][1]	1.29 (1.01) [.16][1]	1.59 (1.22) [.11][1]

NSPECIES	−	+	−.52 (−2.99) [.00][1]	−.54 (−3.59) [.00][1]	−.55 (−3.10) [.00][1]
CONSULT	?		−.37 (−.38) [.70][2]	−.31 (−.41) [.68][2]	−.13 (−.14) [.89][2]
NIPF	?	−	−.21 (−.19) [.85][2]	−.63 (−.86) [.39][2]	−.11 (−.01) [.92][2]
ACCESS	−		−.30 (−1.21) [.11][1]	−.17 (−.89) [.19][1]	−.27 (−1.16) [.12][1]
BUYSIZE	−	−	−.87 (−2.19) [.01][1]	−.79 (−2.25) [.01][1]	−.95 (−2.40) [.01][1]
THIN	+		3.61 (3.57) [.00][1]	3.68 (4.28) [.00][1]	4.04 (3.98) [.00][1]
VALUE	−	+	−.03 (−1.46) [.07][1]	. . .	. . .
Likelihood ratio test			78.5	99.4	75.6
Correct predictions (%)			86.9	86.7	86.9

NOTE.—The dependent variable is PERUNIT: lump-sum = 0, per unit = 1. Numbers in parentheses are asymptotic *t*-values. Numbers in brackets are *p*-values, which indicate the minimum level of test significance for which the hypothesis that the coefficient is zero is rejected. Superscripts on *p*-values indicate whether they are for one-tailed or two-tailed tests.

dictions of the risk-based model but are as predicted by the transaction costs model. The positive coefficient on VOLUME also fails to support the prediction of the risk-based model, and it is not inconsistent with our transaction costs approach.

Additional predictions from the risk-based model are based on the observation that the seller bears more revenue risk on a per unit contract than on a lump-sum contract. By hypothesizing plausible differences in risk aversion (or the ability to diversify the riskiness of selling a timber tract) within the set of buyers and the set of sellers in our sample, we obtain further contrasts in the predictions of the transaction costs approach and a risk approach. The sellers in our sample are relatively small landowners (as compared to large industrial landowners such as Georgia Pacific). Most of them (see table 1) are classified as NIPF landowners: those who typically sell their timber themselves (or with the assistance of a consultant) once every 20 or 30 years. The non-NIPF sales in our sample are typically corporate sales. The NIPF sellers are presumably more risk averse than these other sellers, who can diversify tract-specific risk through more frequent timber sales. Thus a risk-based model would predict a lower likelihood of per unit contracts on NIPF sales. If large buyers (because they purchase more tracts) are assumed to be better able to diversify the risk associated with a particular tract of timber than small buyers, then per unit sales are less likely on sales involving large buyers. Thus the risk-based predictions are that the coefficients on NIPF and BUYSIZE will both be negative. The negative estimated coefficient on BUYSIZE therefore supports the predictions of both the risk model and our transaction costs model. The lack of significance of the coefficient on NIPF fails to support this prediction of the risk model.

Finally, if we add a further standard assumption of the risk aversion literature—decreasing absolute risk aversion—we obtain an additional risk-based prediction opposite to that of the transaction costs model. An increase in the value of the tract should, on average, be associated with greater seller wealth. Given decreasing absolute risk aversion, this increased seller wealth will lead to an increased willingness of the seller to bear the risk of the timber sale. Hence, a risk-based approach predicts an increased likelihood of per unit sales as tract value increases. The negative and significant coefficient on VALUE in table 3 therefore supports the transaction costs model but not the risk model.

Negotiated Sales: Per Unit versus Lump-Sum

Our transaction costs model of the choice between lump-sum and per unit contracts suggests that per unit payments for the quantity of the resource actually harvested are an effective method of reducing presale measurement costs. The discussion also demonstrates that under certain circumstances, landowners will maximize their profits by restricting competition for their timber. The intuition for this, again, is that for any given harvest level, the increase in enforcement costs associated with a higher per unit bid may more than offset the additional revenues associated with a higher bid. There are no similar enforcement cost–based incentives to restrict competition in the analysis of lump-sum sales. We therefore predict a greater reliance on negotiated sales for per unit than for lump-sum contracts.

In our sample of private timber-harvesting contracts, 94 percent of the per unit sales and 20 percent of the lump-sum sales were negotiated. This is a statistically significant difference, which again supports the transaction costs model of contract choice.[42]

IV. Concluding Comments

Empirical studies of the effects of transaction costs on the organization of production are few in number. This paper contributes to that literature by applying a transaction costs–based analysis to the choice of payment provisions in private timber-harvesting contracts. Our empirical results provide strong support for the predictions from such a transaction costs–based analysis, at the same time rejecting several contrasting predictions from a risk-based model. Our analysis also provides a transaction costs explanation for why negotiated sales instead of competitive sales may yield maximum net benefits to the resource owner under some circumstances. Again, our empirical results support this explanation.

Our investigation of the choice between payment provisions for timber focuses on two types of transaction costs: the costs of enforcing desired harvest levels and presale measurement costs. Analyses of contracts for the sale and lease of other natural resources often acknowledge the costs associated with enforcing desired harvest or use levels when per unit or royalty payments are specified. Presale measurement costs, however, typically are ignored. For example, a survey of the literature on public oil-leasing policies indicates that differences in incentives for presale measurement under different payment provisions (a critical component of our model and a potentially important source of dissipation) have been completely overlooked (see, e.g., Leland 1978; Robinson 1984; Mead et al. 1985).

The two types of timber-harvesting contracts that we analyze are extremes on a continuum with "pure" lump-sum sales at one end and

[42] The t-statistic from the test for the equality of the proportion of negotiated per unit and lump-sum sales is 9.56.

"pure" per unit sales at the other. We found no instances of "mixed" timber-harvesting contracts that specified both a lump-sum payment and a per unit payment. By contrast, private and public oil leases include both a lump-sum component (the bonus payment) and a per unit component (the royalty payment). We hypothesize (in Sec. II) that mixed contracts for timber may be absent because of large fixed costs associated with the lump-sum and the per unit components of timber-harvesting contracts. Investigation of this and alternative hypotheses concerning the use of mixed contracts can be accomplished only through detailed interresource comparisons of transaction costs.

References

Akerlof, George. "The Market for 'Lemons': Quality Uncertainty and the Market Mechanism." *Q.J.E.* 84 (August 1970): 488–500.

Alchian, Armen A. "Some Economics of Property Rights." In *Economic Forces at Work.* Indianapolis: Liberty Press, 1977.

Allen, Douglas. "What Are Transaction Costs?" In *Research in Law and Economics,* edited by Richard Zerbe and Victor Goldberg. Greenwich, Conn.: JAI, 1991.

Alston, Lee; Datta, Samar K.; and Nugent, Jeffrey B. "Tenancy Choice in a Competitive Framework with Transactions Costs." *J.P.E.* 92 (December 1984): 1121–33.

Alston, Lee J., and Higgs, Robert. "Contractual Mix in Southern Agriculture since the Civil War: Facts, Hypotheses, and Tests." *J. Econ. Hist.* 42 (June 1982): 327–53.

Barzel, Yoram. "Measurement Cost and the Organization of Markets." *J. Law and Econ.* 25 (April 1982): 27–48.

———. "The Entrepreneur's Reward for Self-Policing." *Econ. Inquiry* 25 (January 1987): 103–16.

Cheung, Steven N. S. "Private Property Rights and Sharecropping." *J.P.E.* 76 (November/December 1968): 1107–22.

———. *The Theory of Share Tenancy.* Chicago: Univ. Chicago Press, 1969. (*a*)

———. "Transaction Costs, Risk Aversion, and the Choice of Contractual Arrangements." *J. Law and Econ.* 12 (April 1969): 23–42. (*b*)

———. "The Fable of the Bees: An Economic Investigation." *J. Law and Econ.* 16 (April 1973): 11–33.

———. "The Contractual Nature of the Firm." *J. Law and Econ.* 26 (April 1983): 1–21.

Coase, Ronald H. "The Nature of the Firm." *Economica* 4 (November 1937): 386–405.

French, Kenneth R., and McCormick, Robert E. "Sealed Bids, Sunk Costs, and the Process of Competition." *J. Bus.* 57 (October 1984): 417–41.

Hallagan, William S. "Share Contracting for California Gold." *Explorations Econ. Hist.* 15 (April 1978): 196–210.

Higgs, Robert. "Race, Tenure, and Resource Allocation in Southern Agriculture, 1910." *J. Econ. Hist.* 33 (March 1973): 149–69.

Johnson, Ronald N. "Auction Markets, Bid Preparation Costs and Entrance Fees." *Land Econ.* 55 (August 1979): 313–18.

Joskow, Paul L. "Contract Duration and Relationship-specific Investments: Empirical Evidence from Coal Markets." *A.E.R.* 77 (March 1987): 168–85.

———. "Price Adjustments in Long-Term Contracts: The Case of Coal." *J. Law and Econ.* 31 (April 1988): 47–83.

Klein, Benjamin; Crawford, Robert G.; and Alchian, Armen A. "Vertical Integration, Appropriable Rents, and the Competitive Contracting Process." *J. Law and Econ.* 21 (October 1978): 297–326.

Leland, Hayne E. "Optimal Risk Sharing and the Leasing of Natural Resources, with Application to Oil and Gas Leasing on the OCS." *Q.J.E.* 92 (August 1978): 413–37.

Libecap, Gary D., and Wiggins, Steven N. "Contractual Responses to the Common Pool: Prorationing of Crude Oil Production." *A.E.R.* 74 (March 1984): 87–98.

Masten, Scott E., and Crocker, Keith J. "Efficient Adaptation in Long-Term Contracts: Take-or-Pay Provisions for Natural Gas." *A.E.R.* 75 (December 1985): 1083–93.

Mead, Walter J.; Moseidjord, A.; Muraoka, D.; and Sorensen, P. *Offshore Lands: Oil and Gas Leasing and Conservation on the Outer Continental Shelf.* San Francisco: Pacific Inst. Public Policy Res., 1985.

Mulherin, J. Harold. "Complexity in Long-Term Contracts: An Analysis of Natural Gas Contractual Provisions." *J. Law, Econ. and Organization* 2 (Spring 1986): 105–17.

Ramsey, J. B. *Bidding and Oil Leases.* Greenwich, Conn.: JAI, 1985.

Robinson, Marc S. "Oil Lease Auctions: Reconciling Economic Theory with Practice." Discussion Paper no. 292. Los Angeles: Univ. California, 1984.

Rucker, Randal R., and Leffler, Keith B. "To Harvest or Not to Harvest? An Analysis of Cutting Behavior on Federal Timber Sales Contracts." *Rev. Econ. and Statis.* 70 (May 1988): 207–13.

Stiglitz, Joseph E. "Incentives and Risk Sharing in Sharecropping." *Rev. Econ. Studies* 41 (April 1974): 219–55.

Umbeck, John. "The California Gold Rush: A Study of Emerging Property Rights." *Explorations Econ. Hist.* 14 (July 1977): 197–226.

U.S. Department of Agriculture. Forest Service. *The South's Fourth Forest: Alternatives for the Future.* Forest Resource Report no. 24. Washington: Government Printing Office, 1988.

Williamson, Oliver E. "The Vertical Integration of Production: Market Failure Considerations." *A.E.R. Papers and Proc.* 61 (May 1971): 112–23.

———. "Transaction-Cost Economics: The Governance of Contractual Relations." *J. Law and Econ.* 22 (October 1979): 233–61.

Wilson, Robert. "A Bidding Model of Perfect Competition." *Rev. Econ. Studies* 44 (October 1977): 511–18.