Scale as a Transaction Cost Variable in the U.S. Biopower Industry

Ira J. Altman
Department of Agribusiness Economics
Southern Illinois University – Carbondale
145G Agriculture Building- Mail Code 4410
1205 Lincoln Drive
Carbondale, Illinois 62901

Peter G. Klein
Department of Agricultural Economics
University of Missouri – Columbia
135D Mumford Hall
Columbia, Missouri 65211

and

Thomas G. Johnson
Department of Agricultural Economics
University of Missouri – Columbia
215A Middlebush Hall
Columbia, Missouri 65211

Draft Date: May 30, 2006

Selected paper for presentation at the American Agricultural Economics Association Annual Meetings, Long Beach, California, July 23-26, 2006

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Ira J. Altman
Southern Illinois University – Carbondale

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Abstract: With increasing interest in renewable energy from agriculture, including biopower and cellulose ethanol, several aspects of the industry must be understood. Study of the organization of the biopower industry represents an under researched area and a new application of transaction cost theory to an emerging industry. Refinement of the theory can also result from challenging applications. This article provides an application of transaction cost economics to the existing United States biopower industry while challenging the empirical convention of excluding production cost variables from transaction cost analysis. Utilizing survey data from 53 biopower generators, scale is modeled as a transaction cost variable in explaining the choice of organizational from. Consistent with transaction cost theory, the probability of observing internal organization is found to be negatively correlated to scale. Given this evidence, this article reconsiders the impact of scale and transaction costs on the choice of organizational from.

Keywords: organizational choice, transaction costs, scale, biopower industry

JEL: L220, L230, L690, Q42

Recent years have seen a growing interest in the development of renewable energy industries for environmental, rural growth and development, and energy security benefits. While the technical aspects of biopower production have been extensively studied (van Loo and Koppejan, 2003 and Klass, 1998), little is known about the economic organization and governance of biopower. How should agro-biopower facilities procure their fuel, from the spot market, through contracts with independent biomass producers, by producing the biomass themselves, or by some combination of external and internal procurement? What are the characteristics of purchase and supply contracts in biopower? Who will be the major players in biopower, existing power companies that convert to biopower production or new entrants? Can incumbents operate multiple facilities, some using biomass and others using non-renewable fuels, or will firms tend to specialize in one technology or the other?

To begin addressing these questions, we focus on a fundamental question in the economic theory of the firm (Coase, 1937), the "make-or-buy decision." Using the transaction cost framework developed by Williamson (1985, 1996), we examine the vertical structure of the biopower industry with survey data from 53 US biopower producers. Our analysis focuses not only on asset specificity—the main variable of interest in the empirical transaction cost literature (Klein, 2005)—but also on the technology of production and the corresponding economies of scale. While transaction cost economics (TCE) allows production costs to affect governance—indeed, in the integrated Riordan and Williamson (1985) model, production costs and transaction costs are determined jointly—in practice, most of the empirical literature has taken production costs as given and focused on transaction costs. Or, as Langlois and Foss (1999) describe the problem, the TCE literature tends to assume that knowledge about production is easily and costlessly acquired, while transacting is fraught with hazards brought about by information and agency costs.

Our results suggest, somewhat surprisingly, that asset specificity is not a statistically significant determinant of vertical integration in biopower. Instead, characteristics of the production process, such as economies of scale, appear to be more important. Moreover, several firms in our sample both make their own biomass and purchase biomass from independent suppliers, a practice difficult to explain within the usual "make-or-buy" framework of TCE. This suggests not only that empirical analysis in the theory of the firm must take scale into consideration, but also that the standard TCE framework may require modification to account for complex arrangements such as simultaneous internal and external procurement.

Literature

Biomass and bioenergy

Biomass and bioenergy researchers have rarely considered organizational issues or applied an adequate organizational theory to this nascent industry. Klass (1998) draws attention to this failure in the area of storage and shipping strategies for wood biomass. The storage and shipping methods prescribed in the literature have not occurred in industry practice (Klass 1988, p.554). Further, van Loo and Koppejan (2003) document examples in Europe where organizational adaptations have solved technological problems. Their work underscores the importance of understanding organizational issues.

Other authors recognize the importance of non-technical barriers in biomass production which could include organizational issues. Roos et al. (1999) and Costello and

Finnell (1998) develop broad-based frameworks for considering organizational issues. They identify critical factors in the choice of organization including the degree of integration, the scale of operation, the degree of competition, the institutions environment such as national and local policy including public infrastructure availability and the perceptual beliefs of key actors. Rösch and Kaltsehmitt (1999) identify similar topics adding insurance issues and efficiency of knowledge and information flows along the supply chain. Lunnan (1997) takes an in-depth view of the institutional environment created by bioenergy policy, and especially how bioenergy policy and more general agricultural policy can be coordinated. Building on this literature, that recognizes the importance of organization in general, this article focuses on applying transaction cost economics and specifically the effects of scale and transaction costs.

More recently Downing et al. (2005) describe the role of agricultural cooperatives in research, financing, and exchange mechanisms in the agro-bioenergy industry. Biopower cooperatives can be regarded as a type of biomass exchange mechanism that could be compared to contracting and spot market systems that also exist in the U.S. biopower industry. However, for this comparison an adequate organizational theory is required.

Overend (1993) provides a description of the main features of a general biomass industry. While Overend identifies only short-term contracts or spot-market procurement as the most viable alternatives, many biomass industries currently rely on captive supplies and integrated systems for fuel procurement. Our survey of the current United States biopower industry reveals that approximately half of the industry relies on vertical integration or self procurement systems. The underlying question is when are spot markets preferable, and when do more integrated procurement systems better serve emerging agro-biopower industries? Again, an adequate organizational theory is required to answer such questions.

Choinière (2002) presents a formal model of the biopower industry. The model analyzes the farmer's investment decision in the presence of learning-by-doing and concludes that underinvestment by farmers and power generators could occur. The choice of organizational form could address the underinvestment problem if the form chosen adequately protects both trading partner's investments.

Some financial feasibility studies have addressed the issue of market organization. But these are generally limited to a footnote or raised as an area of future research. Nelson and Lamb (2002) study the financial feasibility of an anaerobic digester technology and conclude that a single utility should build and operate multiple digesters in multiple locations. This prediction is not born out by experience of the livestock waste-to-power industry, however, where individual livestock operations and power production are being integrated rather than having one business own and operate multiple digesters in multiple locations.

Transaction cost economics

To address these issues, we turn to the transaction cost theory of vertical integration (Joskow, 2005). The key to transaction cost economics (TCE) is the discriminating alignment hypothesis, which states that economic actors will "align transactions, which differ in their attributes, with alternative governance structures, which differ in cost and competence, so as to realize a transaction cost economizing result" (Williamson 1996, p.371). The theory holds that economic agents behave in a way that transactions, which vary in degrees of asset specificity, uncertainty and frequency, are aligned with organizational forms, which can be considered efficient if no feasible alternative can be implemented with net gains. The central problem, in Williamson's framework, is addressing bilateral dependency that an increase in asset specificity or relation specific investments creates.

Riordan and Williamson's (1985) formulation seeks to integrate TCE with neoclassical production theory. Extending the basic TCE model to include production costs, Williamson (1985) and Riordan and Williamson (1985) argue that markets have a production cost advantage over internal organization for different levels of asset specificity because the market can realize economies of scale and scope from aggregation of demand (Williamson 1985, p.92). The market organization can sell the product on a larger scale while internal organization only produces for itself. Internal organization, if it only produces for itself, cannot receive the aggregation benefits. Thus as scale economies increase market organization is more likely than internal organization.

This model can be depicted as a cost-minimization problem, as described below. Market organization and internal organization are assumed to have different transaction costs. When asset specificity is low, market transaction costs are lower than the costs of internal organization, but as asset specificity rises, the costs of market transacting increase more rapidly than the costs of internal organization, such that at some threshold level of asset specificity, internal procurement is the least costly alternative.

These implications are also explained graphically in Williamson (1991). In Williamson's (1991) notation, M is market governance costs, H is hierarchy (or internal organization) and X is used to indicate governance costs of hybrid forms, such as long-term contracting. Adding hybrid simply implies: M(0)<X(0)<H (0) and M'>X'>H'>0. Figure 2 demonstrates Williamson's 1991 model.

[Figure 1 about here]

Figure 1 shows that for k< $\bar{k}_1$ the market will be most efficient, that is, M (k) is the lowest over that range. For values of asset specificity between $\bar{k}_1$ and $\bar{k}_2$, hybrids have the lowest governance costs and will be most efficient. Finally, hierarchy will have the lowest costs for values of k> $\bar{k}_2$.

The lower envelope becomes the collection of low governance costs. The organization forms that correspond with those points will be most efficient. If additional curves were added for multiple organizational structures, including different contractual arrangements (short term, long term, formal, informal), firm organization (joint ventures, strategic alliances, cooperatives), and even government, the resulting lower boundary would be a concave envelope of least cost organizational forms.

The benefit of this version of the model is that comparative statics can be easily conducted. Shift parameters (θ) include technological change, policy and uncertainty. For instance, if policy is implemented that discourage hierarchy (perhaps for monopoly power reasons), this would cause an upward shift in H(k). The change in policy would increase $\bar{k}_2$ and make hierarchy less likely compared to hybrid. However, the incidence of market would remain unaffected.

Two empirical implications emerge from this theory. First, asset specificity is positively correlated with vertical integration and negatively correlated with spot market organization. Second, scale economies are positively related to market procurement and negatively related to vertical integration. Thus, according to the theory, given economies of scale the market organization is more likely in the biopower industry as scale increases because internal organization is unable to realize aggregation benefits realized by the market.

Empirical research in transaction cost economics

Previous empirical research in a variety of industry settings has tended to support the basic predictions of TCE, particularly regarding the relationship between asset specificity and vertical integration. Scale has not normally been incorporated into TCE models, however, and those that do use scale as an explanatory variable find mixed support for TCE theory regarding the impact of scale on the choice of organizational form (Wilson, 1980, Wiggins and Libecap, 1985, and James et al., 2005). Empirical studies that test TCE range in the level of focus and type of analysis. Types of analyses include qualitative case studies, quantitative case studies and cross sectional analyses (Shelanski and Klein, 1995). The focus has ranged from contract provisions, to the governance level, to the institutional environment. The types of industries analyzed range from the auto sector, airline industry, coal markets and oil and natural gas industries. Shelanski and Klein (1995) and Boerner and Macher (2001) provide a broad review of this literature.

In most of the empirical literature the choice of organizational form is modeled as some function of asset specificity and other explanatory variables. Cross-sectional analyses often utilize a logit or probit model to deal with the qualitative nature of the dependent variable. Some contractual attributes, such as prices, length of contracts, or other measurable contract provisions, can be modeled as continuous variables, though the presence of a contract provision is typically measured as a qualitative variable.

Studies that use scale or size as a transaction cost explanatory variable include Saussier (2000), who uses scale as an indicator of asset specificity. The capacity and other features of ships are used to indicate the level of physical asset specificity. Wiggins and Libecap (1985) find that, contrary to TCE, that firm size is positively related to vertical integration in oil field organization. In agriculture, the use of contracts and vertical integration are found to be positively correlated with farm size (James et al.,2005). In other work, Wilson (1980), uses the size of fishers as an indicator of trust. Anecdotally, larger fishers tend to have long term reciprocal relationships with buyers. Again size is found to be positively correlated with hierarchy.

Thus support for scale as transaction cost variable is weaker than support for asset specificity. Results from our data do support the statistical significance and predicted sign of scale. As the scale of a power plant increases it is more likely to use external procurement for purchasing its biomass fuel.

Empirical Results

Data

Our data come from a biopower generator survey conducted by the University of Missouri-Columbia. We began with a list of 210 firms identified by the Energy Information Administration as producing power from wood or agricultural biomass sources in 2003. The Energy Information Administration conducts an annual questionnaire of all power plants that have a capacity of one megawatt or greater. Of the 210 companies, 12 have plants that are listed as retied, leaving 198 in active production. Of the active-production plants, 164 are listed as operable, 17 are on stand by and 17 are listed as out of service. Mail surveys were sent to the 198 active companies and 53 responded, a 27 percent response rate.

In the biopower industry, key assets include the power plant and storage, collection, and transportation equipment. The degree of asset specificity of these assets varies. Thus the theory would suggest the types of organizational arrangements should vary with the level of asset specificity.

There are three general organizational alternatives. The first is vertical integration or internal procurement. Vertically integrated systems typically involve the biomass producer integrating forward into biopower production and in more rare cases power producers backward integrating into biomass production. A second organizational choice is external procurement. This system involves independent power producers purchasing biomass as fuel for their generation needs from independent biomass producers. This category includes both the use of spot markets, formal contracts, and informal arrangements. Third, firms can procure part of their fuel need from in-house sources and source the rest externally.

These organizational choices are of interest when the choice of scale is also taken into consideration. Why do some firms choose a smaller scale and internal procurement combination while some choose a larger scale and both internal and external procurement?

Of our 53 sample firms, 28 rely on vertically integrated systems or a system that uses internal procurement. These companies include forestry, wood, and pulp and paper manufactures as well as food and agricultural companies that have integrated forward into biopower production. Rather than sell their waste products to other processors or dispose of them, they have chosen to utilize their wastes in biopower production. Thirteen of the sample firms procure all their biomass externally, using spot markets or contracts. These companies are generally traditional power companies that have chosen to enter biopower production. Of these 13, three rely on spot markets while the other 10 use contracts ranging from 3 months to 20 years in length.

The remaining 12 firms use both internal procurement and external procurement. These include wood and agricultural manufacturing companies that have increased the scale of their power plants beyond their own waste capacity or utilities that have partially integrated into fuel production.

Determining whether the transaction cost theory is a reliable predictor of organizational form in the biopower industry is challenging. Secondary data on variables such as asset specificity are unavailable and primary data collection techniques imperfect.

From the perspective of the power generator a key variable is the flexibility of the generation technology with respect to the use of fossil fuels (van Loo and Koppejan, 2003). If the generator can easily convert to using fossil fuels the degree of physical asset specificity of the power plant would be low; the value of alternative uses of the power plant is high. If it is difficult and costly to convert the power plant to the use of fossil fuels the degree of asset specificity would be high; the value of the power plant in alternative uses is low. In the biopower survey generators are asked to rate the flexibility of their power plant as either: highly flexible, their power plant could easily be converted to use mainly fossil fuels without adjustments and delay, moderately flexible, their power plant could use mainly fossil fuels after minor adjustment and delays, or highly inflexible, their power plant can not use mainly fossil fuels without major adjustment or delay. Table 1 summarizes the responses to this question.

[Table 1 about here]

Scale of power plants was measured by the level of biomass inputs the generator uses per year. The scale of the plants could be measured in various ways. There are different measures of generation capacity such as, summer, winter, and name plate capacity. However, for a study of organizational form of biomass procurement, the quantity of biomass fuel used may be the most appropriate to determine the scale relationship to organizational form choice. It is unclear what capacity in Mega Watts indicates especially if only a small percentage of that power is generated from biomass. The range of biomass fuel used is a low of 70 tons per year and a high of 1.4 million tons per year. The average use is 225 thousand tons with a standard deviation of 261 thousand tons. Table 2 summarizes these statistics.

[Table 2 about here]

Another explanatory variable included is a spatial asset specificity variable measured as the average hauling distance in increments of 0-10, 10-50, and over 50 miles. Following Joskow's (1985, 1987, 1990) work on coal-fired plants, high average hauling distances are expected to be positively related to external procurement and negatively correlated to internal procurement. Table 3 summaries this variable.

[Table 3 about here]

A final variable considered in this analysis is generation technology. Most power plants that use biomass use a steam turbine technology. However, the boiler technology may be co-fire, where a percentage of biomass fuel can be used with fossil fuels or direct fire where mainly biomass is used (van Loo and Koppejan, 2003). There are 15 of 53 who indicate the use of a co-fire technology while 34 of 53 indicated they use direct fire. Also, four of 53 indicated another technology, such as internal combustion or gasifier. While we have no prediction on the sign of this variable, however, we include it as a control for possible relationships between the technology chosen, asset specificity, and scale. Table 4 summarizes the explanatory variables used in this analysis and the expected signs.

[Table 4 about here]

Analytical methods

Because our dependent variable is categorical, we use a multinomial logit model.[1] In this model firm i face J unordered choices. The response probability, that firm i chooses choice j (P_{ij}) is modeled as: $P_{ij} \equiv P(Yi = j|X) = \dfrac{\exp(\beta_j X_i)}{1 + \sum_{j=1}^{J} \exp(\beta_j X_i)}$ where P_{ij} is the probability Y_i=j or that firm i chooses category j given the explanatory variable vector X, β_j is the estimated parameter vector and X_i is the observed characteristic vector of firm i.

In specific form, there are three choices of organizational form as the explanatory variable, so j = 0,1,2 and i = 53. The log likelihood function for this multinomial logit can be expressed as: $\ln L = \sum_{i=1}^{53} \sum_{j=0}^{2} d_{ij} \ln P_{ij}$ where d_{ij}=1 if firm i choose organizational form j.

In results from this model the p-values are valid making significance tests meaningful while the signs and magnitudes of the coefficients are not valid. In order to get the partial marginal effects for continuous variables they can be calculated as: $\dfrac{\partial P_{ij}}{\partial X_k} = P_{ij}\{\beta_{jk} - [\sum_{h=1}^{J} \beta_{hk} \exp(X\beta_h)] / g(X, \beta)\}$ where β_{hk} is the kth element of β_h and

[1] We considered, but rejected, using a nested logit and ordered probit or logit models. A nested logit would be appropriate in an organizational assessment that featured both the governance level and contract level. Choices of governance could be featured at the branch level while contract choices could be on the twig level. However, we lack sufficient details on the contractual characteristics to specify such a nesting structure. We do not use an ordered probit or logit because our dependent variables lack an inherent rank ordering.

$g(X, \beta) = 1 + \sum_{h=1}^{J} \exp(X\beta_h)$, and the marginal effects of limited explanatory variables are calculated as the difference between probabilities (Wooldridge, 2002).

Complicating issues include endogeneity such as simultaneity of organizational form and asset specificity, unobserved variables such as transaction costs and missing or biased observations, and causality between asset specificity and organizational form. Saussier (2000) treats asset specificity as an explanatory variable explaining the choice of organizational form (the choice of contract completeness) in the French power industry but also models asset specificity as a simultaneous dependent variable in a two-stage least squares model. Joskow (1987) and Masten and Crocker (1985) address the truncated data issue with a tobit maximum likelihood regression technique. Masten et al. (1991) address the issue that transaction costs are not usually observed and linked to performance. Linking transaction cost arguments to such performance measures as profitability and failure rates would improve the legitimacy of results. However, studies that address these types of issues tend not to influence the support of the theory from those data but rather reinforced the validity of the tests.

Given the limited data set of 53 observations, and various limited explanatory variables (scale is the only continuous variable), we focus on testing the basic theory against these data and interpreting the marginal effects. Addressing endogeneity and related issues will be the focus of future research with more and better data.

Results

In this model the probability of the choice of organizational form (ORGFROM) is regressed against four key explanatory variables: flexibility with respect to fossil fuel use (FLEXFF) as a measure of physical asset specificity, average hauling distance (AVEHD) as a measure of spatial asset specificity, scale of the plant (SCALE) measured in tons of biomass used per year and technology type (TECHTYPE). Results are reported in table 5 and marginal effects in table 6.

These results show support for transaction cost economic theory. In this model, internal procurement (0) is the comparison group. Average hauling distance and scale are statistically significant at the 90% confidence level when external procurement (1) is the alternative organizational form. When procurement type (2) is the alternative choice only scale is statistically significant. This may indicate that there is not as much of a difference between internal procurement only and both internal and external procurement in terms of flexibility. The model as a whole is statistically significant at the 95% level.

[Table 5 about here]

The marginal effects are also consistent with TCE. The marginal effects of the two asset specificity variables, flexibility with respect to fossil fuels and average hauling distance, have the signs expected when following the theory. Also, the scale of the plant is found to increase the probability of observing external organization and decrease the probability of internal organization. This is also consistent with the theory. Table 6 reports these marginal effects.

[Table 6 about here]

The sign of the flexibility variable is consistent with the theory. A change in flexibility from inflexible to flexible (Min to Max) increases the probability of observing external procurement by 22% and decreases internal procurement by 18%. That is, a change from high asset specificity to low asset specificity, as measured by the flexibility indicator increases the probability of observing external procurement by 22% and decreases the probability of observing internal procurement by 18%. Similarly, when average hauling distance increases from 0-10 miles to 50+ miles the probability of observing external procurement increases by 31% and internal procurement decreases by 38%. In other words, a change from high spatial asset specificity to low spatial asset specificity is associated with an increase in the probability of external organization and a decrease in the probability of internal organization.

Scale also has the correct sign. Williamson (1985) and Riordan and Williamson (1985) argue that market procurement has a scale advantage over internal organization because of demand or supply aggregation benefits. This implies that external procurement is more likely when scale increases. In this case it would be supply aggregation benefits that give the organizational form market a scale advantage. Thus as scale increases the probability of observing market should increase. Consistent with this account, we find that a 10,000 ton increase in scale increase the probability of external procurement by 3.7% and decreases the probability of internal organization by 10%. A 10,000 ton change from the mean (-+1/2) reveals a similar 3.5% increase in observing external procurement and 10% decrease in observing internal organization. A one standard deviation change from the mean reveals a 9% increase in observing external procurement and a 26% decrease in observing internal organization. Finally, a change in scale from min to max increases the probability of observing external by 3.9% and the both category by 71% while decreasing the probability of internal organization by 75%. The changes in all of these probabilities support the theory that market or external procurement will have a scale advantage over internal organization.

Implications

Our analysis suggests that TCE can be useful in explaining not only the choice of organizational form but also scale of a processing facility. Consider a hypothetical example of an existing wood or agriculture manufacturer that has insufficient waste products to meet the minimum efficient scale; the choice of scale of a biopower generation facility without transaction costs will lead to a larger scale to receive the benefits of scale economies while the manufacturer uses both internal procurement and external procurement. Yet empirical evidence suggests many manufacturers choose a smaller scale and internal organization only. Adding transaction costs to the analysis helps explain this phenomenon.

Beyond supplies of its own waste products, wood and agricultural manufacturing companies would have to incur additional transaction costs to procure the additional supplies. The question then becomes are these additional transaction costs more than the scale economy benefits of increasing scale. If the transaction costs are more than the scale economy benefits the manufacture chooses the smaller scale and the internal organization only option, otherwise the manufacture chooses a larger scale and both internal procurement and external procurement. This argument is supported by figure 2.

[Figure 2 about here]

In Figure 2, AC_1 are the average costs of biopower production without external transaction costs taken into account, AC_{TC}, the average costs of biopower production with transaction costs taken into consideration, and X^o is the current waste product or biomass input into the biopower production stage. It is assumed that X^o is fixed and determined by the primary wood or agricultural manufacturing stage. Without taking transaction costs into consideration the model would predict biomass input use of X^* and internal procurement up to X^o and external procurement beyond up to X^* (point B); there are no transaction costs to retrieving external supplies and the cost minimizing firm will choose a larger scale to gain the economies of scale benefit while choosing to use both internal and external procurement.

However, when transaction costs are taken into consideration the solution is indeterminate (as drawn point A and point C have equal average costs); it depends on the tradeoff between transaction costs and scale economies. Taking both transaction costs and economies of scale into consideration will have implications both for the scale and type of organizational form chosen.

Complicating factors include the shape of the transaction costs curve or how transactions vary with scale. While much of the transaction cost literature focuses on the relationship between transaction costs and asset specificity, the tradeoff between transaction costs and scale may be equally important. To simplify the discussion here, a flat transaction cost curve is assumed. Further, allowing asset specificity to change will result in multiple potential transaction curves for different organizational forms akin to figure 1 in this article. This will influence the shape of the transaction cost curve and hence impact the average cost curve. Finally, the assumption that the existing supply of biomass waste X^o is less that the minimum efficient scale could also be challenged.

An additional implication of our research is that the factors leading to external procurement do not necessarily induce firms to procure all the relevant inputs on the market. That is, some firms choose to "make and buy." He and Nickerson (2006) document a similar phenomenon in the for-hire trucking industry, where some carriers use both employee drivers and contract drivers at the same time. They suggest that concerns over efficiency, appropriability, and competition lead firms to organize each haul independently, rather than choosing a single mode of organization for an entire class of transactions. Our results suggest, similarly, that procurement decisions are more complicated than the standard TCE models suggest and that economies of scale are an important factor.

Conclusions

Organizational challenges to bioenergy industries may benefit from the application of transaction cost theory just as further refinement of the theory may benefit from challenging applications. This article attempts to link these two areas.

While the biomass and bioenergy literature does address organizational and commercialization issues, in passing, an adequate organizational theory is lacking. Organizational economics and transaction cost economics in particular has evolved to the point where application to immature and developing industries seems appropriate. However, theoretical questions such as the role of scale in the transaction cost model still exist.

In an attempt to address these issues transaction cost economics is applied to the United States biopower industry with a special focus of the effect of scale on the choice of organizational form. Survey data from biopower generators reveals several important variables such as physical asset specificity, spatial asset specificity and scale of generation facilities. These variables are regressed in a multinomial logit model against the choice of organizational form. Contrary to preliminary empirical evidence in the transaction cost literature scale is found to support the transaction cost theory.

Given this evidence both transaction costs and economies of scale are reconsidered in the choice of organizational form and scale of biopower generation facilities. Transaction costs and economies of scale are demonstrated to be two key trade-offs in these decisions.

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Table 1: Fossil Fuel Flexibility in the Sample of Biopower Generators

Flexibility	*Frequency*	*Percent*	*Cumulative Frequency*
Highly Inflexible	26	49.05	49.05
Highly Flexible	12	22.64	71.69
Moderately Flexible	15	28.30	100.00
Total	53	100.00	

Table 2: Summary Statistics– Scale

Variable	*Observations*	*Mean (Tons/year)*	*Standard Deviation (Tons/year)*	*Minimum (Tons/Year)*	*Maximum (Tons/year)*
Scale	53	225,071.7	261,342.8	70	1,445,937

Table 3: Frequency of Average Hauling Distances

	Frequency	*Percent*	*Cumulative Frequency*
0-10 miles	14	26.42	26.42
11-50 miles	25	47.17	73.58
Over 50	14	26.42	100.00
Total	53	100.00	

Table 4: Explanatory Variables and Expected sign

Explanatory variable	*Expected sign*
Flexibility to fossil fuel use	Decrease in the probability of observing internal organization
Scale	Decrease in the probability of observing internal organization
Average hauling distance	Decrease in the probability of observing internal organization
Technology type	undetermined

Table 5: Regression Results: Multinomial Logit

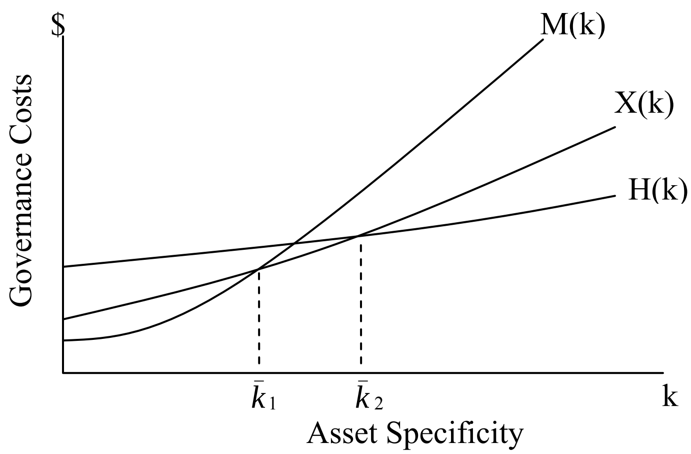
Log likelihood:	-44.523375			Number of observations:	53
				LR chi2(8):	18.87
				Prob > chi2:	**0.0155**
				Pseudo R2:	0.1749
Organizational Form External	**Coefficient**	**Standard Error**	**P>|z|**	**[95% Conf. Interval]**	
FLEXFF	.6245263	.4469447	0.162	-.2514692	1.500522
AVEHD	1.080492	.5978011	**0.071**	-.0911766	2.252161
SCALE	3.52e-06	1.87e-06	**0.060**	-1.50e-07	7.18e-06
TECHTYPE	-.8807087	.7510431	0.241	-2.352726	.5913089
CONS	-2.898541	1.021664	0.005	-4.900966	-.8961153
Organizational Form Both					
FLEXFF	.0789956	.4739609	0.868	-.8499506	1.007942
AVEHD	.5419809	.5439205	0.319	-.5240838	1.608046
SCALE	4.76e-06	1.86e-06	**0.010**	1.12e-06	8.40e-06
TECHTYPE	.4868234	.5668151	0.390	-.6241138	1.597761
CONS	-2.7934	.947754	0.003	-4.650963	-.9358361

Outcome organizational form equal to 0 (internal organization) is the comparison group

Table 6: Marginal Effects of Multinomial Logit Model

mlogit: Changes in Predicted Probabilities for ORGFORM

FLEXFF				
	Average Change	**External**	**Both**	**Internal**
Min to max	.14705233	**.22057848**	-.04019131	**-.1803872**
AVEHD				
Min to max	.25442452	**.31146399**	.07017279	**-.3816368**
SCALE				
Min to max	.50094266	**.03968221**	**.71173181**	**-.75141397**
-+ 1/2	6.954e-07	**3.576e-07**	6.557e-07	**-1.073e-06**
-+ sd/2	.17424998	**.09363356**	.1677414	**-.26137498**
Marginal effect	6.822e-07	**3.709e-07**	6.524e-07	**-1.023e-06**
TECHTYPE				
Min to max	.17964793	**-.25556941**	.26947188	**-.01390249**



Source: Adapted from Williamson, 1991

Figure 1: Governance costs as a function of asset specificity

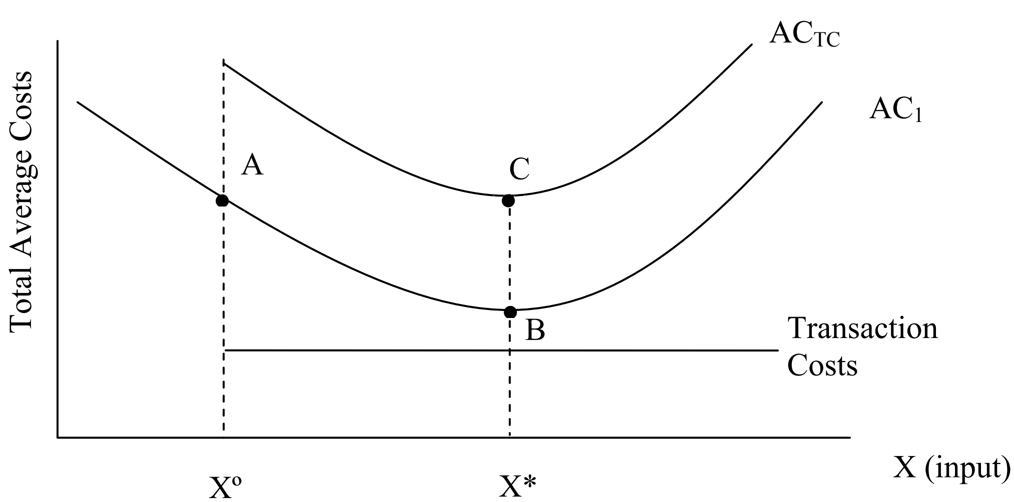


Figure 2: Average costs and transaction Costs