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DETERMINANTS OF VERTICAL INTEGRATION: AN EMPIRICAL TEST*

MARVIN B. LIEBERMAN

This paper tests models of vertical integration, with emphasis on incentives that arise from transactions costs and demand variability. The tests are based on a logit analysis of firms' backward integration choices in a sample of 34 chemical products. The results are consistent with recent transactions cost theories and the demand variability model proposed by Carlton [1979].

I. INTRODUCTION

MARKET imperfections of various types can create incentives for firms to integrate vertically. Theoretical studies have shown that integration may be induced by transactions costs, imperfect competition, imperfect information and other factors.[1] Empirical studies have focused primarily on transactions cost motives for integration and have typically found strong support for the transactions cost theory.

Empirical researchers have seldom considered the incentives for integration arising from demand variability—the common notion that firms integrate backward to assure stable sources of supply. This paper assesses demand variability and transactions costs as factors jointly affecting the likelihood of backward integration. A logit analysis of backward integration is performed using data on producers of 34 organic chemical products. The results confirm that transactions costs and demand variability have both been important determinants of integration in the chemicals manufacturing sector.

Unlike many prior studies that have relied on crude proxies for the presence of integration, this study incorporates direct observations of backward integration at the level of individual plants and firms. Moreover, the sample includes detailed information on cost structures and historical demand conditions, which theory suggests should influence firms' integration decisions. The chemicals manufacturing sector offers an attractive context for studying demand variability as a determinant of integration, given the availability of data on the annual production of numerous upstream and downstream products.

The paper is organized as follows. The next section summarizes the transactions cost and demand variability theories, which are used to derive a

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[1] See Perry [1989] for a recent review of the vertical integration literature.

series of testable hypotheses. Section III describes the data and measures. In Section IV, logit analysis is used to assess the probability of integration as a function of sunk costs, market concentration and demand variability. Section V offers a summary of findings and some brief conclusions.

II. MODELS AND HYPOTHESES

II(i). *Transactions cost models*

In the transactions cost theories of Williamson [1975, 1986] and Klein, Crawford and Alchian [1978], incentives for vertical integration stem from problems of small numbers bargaining. Such problems can arise given either: (1) small numbers of firms in the market, *ex ante*; or (2) sunk investments which create lock-in between buyer and seller, *ex post*. In the latter case, each party to the transaction has the potential to expropriate quasi-rents derived from the other firm's investments. In effect, the parties become locked into a bilateral monopoly relationship based on the extent of "asset specificity." If allowances for future contingencies can be adequately specified, long-term contracts can be written to avoid potential hold-up problems. Otherwise, firms must resort to integration.

This paper tests three hypotheses pertaining to the likelihood of backward integration, as implied by the transactions cost theory. The predicted effect of (*ex ante*) seller concentration can be formalized as:

(H1) *Downstream producers are more likely to integrate backward when the upstream market contains only a small number of suppliers.*

Evidence in support of this hypothesis has been obtained in various prior studies (e.g. MacDonald [1985]; Levy [1985]; Martin [1986]; Walker and Weber [1987]; and Caves and Bradburd [1988]).

A second hypothesis pertains to the influence of asset specificity:

(H2) *Backward integration is more likely when the downstream firm must commit to large sunk investments in (transaction-specific) assets.*

If the firm fails to integrate, the rents associated with these assets can, under the conditions described by Klein, Crawford and Alchian [1978], be appropriated by the upstream supplier. Empirical evidence consistent with this prediction has been obtained in numerous studies, including Monteverde and Teece [1982], Stuckey [1983], Joskow [1985], and Caves and Bradburd [1988].

A third hypothesis implied by the transactions cost theory is:

(H3) *Backward integration is more likely when the input in question accounts for a large proportion of total cost.*

If the input constitutes a minor proportion of total cost, even a large relative price premium paid to its supplier will have little effect on the profits of the firm. In a prior study of integration, Caves and Bradburd [1988] found the input cost share to have the strongest explanatory power of all the measures tested. This cost share hypothesis, while implied by the transactions cost theory, is also consistent with other theories of vertical integration.

II(ii). *Demand variability*

Several theoretical studies have shown that vertical integration can be induced by fluctuations in demand.[2] Carlton [1979] has proposed a model in which firms integrate to minimize the total costs attributable to demand fluctuations. Firms with relatively stable input requirements will choose to integrate backward to avoid paying a premium for the input which is induced by the fluctuating demand of other buyers.

A critical assumption of Carlton's model is that prices are imperfectly flexible; upstream prices must be set before downstream demand is revealed.[3] Input prices exceed marginal cost under most demand conditions, given the requirement that independent input suppliers must recover their capacity costs. In effect, downstream firms pay a premium to independent upstream suppliers to compensate for the costs of maintaining buffer capacity.

Carlton shows that under certain conditions, downstream firms will integrate backward for at least some portion of their input requirements. One interesting equilibrium is that of partial integration: firms integrate backward "to satisfy their 'high probability' demand and use the (input) market to satisfy their 'low probability' demand" (Carlton [1979, p. 198]). Carlton's model formalizes the notion discussed in the business literature (e.g. Chandler [1977]; Porter [1982, p. 319–320]) that it is often profitable for firms to maintain an internal supply operation which runs at full utilization, allowing outside suppliers to absorb fluctuations in demand.[4]

Carlton's model has two implications that should be verifiable empirically but have never been tested. The central prediction of the model is that backward integration "become(s) attractive when the other input demanders have high variability in their input demand and thereby drive up the input price."[5] Stated more formally:

(H4) *A firm is more likely to integrate when the other buyers of the input have high variability in demand.*

[2] Demand fluctuations alone are generally not sufficient to induce vertical integration; most models assume the additional presence of market imperfections. One exception is Perry [1984], described below.

[3] Carlton [1986, 1989] offers evidence that such price inflexibility is widespread in industrial markets.

[4] In his formal model, Carlton assumes that producers are identical, which leads to the result that all firms choose the same degree of integration. Heterogeneous producers would, however, differ in their integration choices.

[5] Carlton [1979], p. 204. Green [1986] obtains a similar result in a model based on price inflexibility and rationing.

In particular, this will occur when the input has multiple uses, some of which experience large fluctuations in demand. A second implication, based on the law of large numbers, is that "firms are less likely to integrate when they form a small part of total demand for the input, since they would lose the risk pooling economies of large markets as they integrate". This prediction can be formalized as the following hypothesis:

(H5) *A firm that accounts for a large fraction of total demand for the input is more likely to integrate.*

Other models of vertical integration in environments with demand or supply variability offer different predictions. Perry [1984] has proposed a model in which upstream and downstream markets are perfectly competitive, but there is an exogenous net supply of the upstream good which is random. Perry shows that physical economies of vertical integration can be offset by the profits achievable when independent firms are able to adjust their output to accommodate fluctuations in the price of the intermediate good. Greater output variability in the upstream market shifts the equilibrium, reducing the number of firms that are vertically integrated. This prediction is the opposite of hypothesis (H4) derived from the Carlton model.

Blair and Kaserman [1983] have developed a model that assumes risk aversion on the part of the firm. As interpreted by Caves and Bradburd [1988, p. 273] one implication of the model is that "risk-averse parties will be deterred from vertical integration by quantity disturbances to the buying and selling industries that are positively correlated over time". In the context of backward integration, this translates into the following hypothesis:

(H6) *The likelihood of backward integration is diminished by the presence of demand fluctuations in the input market that are correlated with fluctuations in the firm's downstream market.*

Note that this prediction differs from hypothesis (H4) implied by the Carlton model. In the Carlton model, backward integration becomes more attractive as the variability in input demand rises, assuming that this upstream variability is *uncorrelated* with fluctuations in the firm's downstream market. In the Blair and Kaserman model, integration is discouraged by demand variability that is *correlated* between the two markets. Thus, the models differ in the type of variability that is relevant as well as the direction of effect. To test this distinction in the empirical analysis below, upstream output variability is decomposed into correlated and uncorrelated components.

In addition to variability in the upstream market, volatility in downstream demand may reduce incentives for integration. Harrigan [1983, p. 315] proposes that "other things constant, vertical strategies undertaken within volatile industry settings should involve lesser degrees of internal transfer, lower ownership stakes, and fewer integrated activities".[6] This suggests the following hypothesis:

(H7) *Firms are less likely to integrate backward when they face large fluctuations in downstream demand.*

This hypothesis is tested below using a measure of downstream output variability.

Such relations between demand variability and vertical integration have been considered in very few empirical studies. Hypotheses (H4) and (H5) have not, in general, been tested. Caves and Bradburd [1988] found more integration when sales were highly correlated between the upstream and downstream stages, which is inconsistent with hypothesis (H6). However, they judged that the observed association was not causal. Based on an assessment of case studies, Harrigan [1983] concluded that firms in 'volatile' industries avoid vertical integration, which is consistent with hypothesis (H7). Walker and Weber [1987] found that high uncertainty with respect to volume contributed to backward integration when the number of potential suppliers was small, but not when the number was large. This can be viewed as consistent with hypothesis (H7) and to some extent (H5) (integration being less likely when the firm constitutes only a small proportion of total demand for the input).[7]

III. DATA AND VARIABLES

The data sample covers US producers of the 34 chemical products in Table I. These products were selected from the larger universe of organic chemicals, based on data availability and other criteria.[8] For each product, Table I lists the primary upstream chemical input, the number of producers at each stage, and the incidence of backward integration at the end of 1980.

Markets in the sample were typically characterized by oligopoly. All products had at least three producers; some upstream inputs, such as benzene,

[6] Such incentives can also arise in the Carlton model. If downstream producers face independent demand fluctuations, then greater variability can increase the risk-pooling benefits of using the input market (i.e. remaining unintegrated).

[7] Although not relevant to the specific hypotheses tested in this paper, several empirical studies suggest that integration often reduces systematic risk. Helfat and Teece [1987] and Spiller [1985] found declines in firms' systematic risk following vertical mergers; Greening [1976] and Mitchell [1976] found that integration reduced firms' cost of capital.

[8] The sample includes all organic chemicals that met the following criteria: (1) The chemical was not manufactured primarily as a by-product; (2) Data on components of production cost were published in the 1976 SRI *Process Economics Program Yearbook*; (3) Producer capacities for the product and the main upstream input were listed in the 1981 SRI *Directory of Chemical Producers*; (4) Annual data on industry output of the product and its main upstream input over the 1970–80 period were published in *Synthetic Organic Chemicals*; (5) Virtually all producers used similar production processes and the same primary input. (A small number of producers using different inputs or production methods were excluded from the sample.)

ethylene and propylene, had more than two dozen. The sample contains relatively few observations with small numbers of input suppliers.[9]

In many industries forward and backward integration decisions can be regarded as symmetric (Salinger [1989]). Nevertheless, the analysis in this study focuses solely on backward integration. This is because the nature of vertical relationships in the chemicals sector makes it difficult to test forward integration hypotheses. The difficulty arises from the data requirements of binomial logit analysis: one must be able to identify a unique market into which the firm might have integrated. For most chemical manufacturing processes the principal input is unique and easily identified, but the chemical output can be used in a variety of downstream applications. The existence of multiple downstream markets into which integration might have occurred greatly complicates any forward integration test procedure.[10]

III(i). *Dependent variable*

The dependent variable is a zero/one dummy that records, for each downstream product and producer, whether or not that firm manufactured its primary chemical input at the end of 1980. Given the data available, two related measures of backward integration were computed: (1) *plant-level* integration, and (2) *firm-level* integration. The plant-level measure equals one if the firm produced both the primary input and the downstream product at the same geographic site. The firm-level measure equals one if the firm produced the input at any of its plant sites in the United States. The plant-level dummy is generally the more accurate indicator of integration, given that captive inputs are usually converted at the site where they are produced.[11]

While existence of upstream and downstream facilities under common ownership is reasonable evidence of integration, it does not imply that the direction of integration was backward. To restrict the sample to (predominantly) firms that faced backward integration decisions, oil companies were dropped from the sample. Most oil companies, given their upstream base, were pursuing forward integration. The deletion of oil producers from the sample reduced the total number of company-product observations from 276 to 203. Of the firms remaining in the sample, about 75% had their major base of operation in the chemical industry.

While the integration dummies developed here have advantages over many

[9] The analysis assumes that the number of suppliers observed in 1980 is approximately the number anticipated by downstream producers when they made their integration decisions. The number of upstream firms operating in the mid-1960s and 1970s was generally smaller than the number observed in 1980, but not substantially so.

[10] The SRI publication, *Chemical Origins and Markets*, identifies the linkages between chemical process inputs and outputs.

[11] In many instances where integration was shown only at the firm level, the captive input was being used to make a different downstream product.

TABLE I
PRODUCTS INCLUDED IN THE SAMPLE

Downstream Product	*Number of Producers:*		*Fraction of Non-Oil Firms Integrated:*		*Upstream Product*	*Number of Producers*
	Total	*Non-Oil*	*Firm-Level*	*Plant-Level*		
2-Ethylhexanol	5	4	0.50	0.50	Propylene	38
ABS resins	8	7	0.57	0.14	Styrene	10
Acrylic Acid	4	3	0.33	0.33	Propylene	38
Acrylonitrile	4	3	0.67	0.33	Propylene	38
Adipic Acid	4	3	0.00	0.00	Cyclohexane	9
Bisphenol A	5	4	1.00	0.75	Phenol	17
Butyl Acrylate	4	4	1.00	1.00	Acrylic Acid	4
Caprolactam	3	2	0.00	0.00	Cyclohexane	9
Cumene	13	4	0.75	0.50	Benzene	35
Cyclohexane	9	3	1.00	1.00	Benzene	35
Dimethylterephalate	3	3	0.33	0.00	p-Xylene	10
Dinitrotoluene	5	5	0.00	0.00	Toluene	29
Ethyl Acrylate	4	4	1.00	1.00	Acrylic Acid	4
Ethylbenzene	11	6	0.67	0.33	Benzene	35
Ethylene Glycol	12	9	1.00	1.00	Ethylene Oxide	12
Ethylene Oxide	12	10	0,70	0.70	Ethylene	27
Formaldehyde	14	12	0.50	0.16	Methanol	8
Isopropanol	4	1	1.00	1.00	Propylene	38
Methyl Methacrylate	3	3	0.00	0.00	Acetone	16
n-Butanol	8	5	0.40	0.40	Propylene	38
Nylon 6 Fibers	10	10	0.20	0.00	Caprolactam	3
Phenol	17	7	0.42	0.14	Cumene	13
Phosgene	13	13	0.54	0.38	Chlorine	32
Phthalic Anhydride	8	5	0.20	0.00	o-Xylene	8
Polyethylene resins-HD	14	8	0.62	0.37	Ethylene	27
Polyethylene resins-LD	14	7	1.00	1.00	Ethylene	27
Polystyrene resins	17	12	0.42	0.08	Styrene	10
Polyvinyl Alcohol	3	3	0.33	0.33	Vinyl Acetate	5
Polyvinyl Chloride	20	18	0.28	0.17	Vinyl Chloride	12
Propylene Glycol	5	2	1.00	1.00	Propylene Oxide	3
Styrene	10	6	1.00	1.00	Ethylbenzene	11
SBR Rubber	8	2	0.50	0.50	Butadiene	14
Vinyl Acetate	5	4	0.75	0.50	Acetic Acid	8
Vinyl Chloride	12	9	0.22	0.22	Ethylene	27
Total	276	203				

of the proxy measures used in prior studies, integration decisions were not as dichotomous as the use of dummy variables may suggest. In the chemical industry, non-integrated producers seldom rely on spot market transactions; most arms-length purchases take the form of contracts, which vary in duration. Prior to the 1973 oil embargo, annual, fixed-price contracts were most common; since then, contracts have tended to be longer-term and more complex.[12] Thus, the "non-integrated" firms in the sample spanned a range of

[12] Such contracts typically exhibit short-term price inflexibility, which gives credence to the main assumption of the Carlton model.

contractual linkages. Moreover, some "integrated" firms produced all of their input requirements, some produced only part, and others produced a net surplus that was sold in the input market.

For each product in the sample, Table I reports the percentage of producers (excluding oil companies) that were backward integrated. Of the 203 downstream producers in the sample, 39% were integrated at the plant level and 53% were integrated at the firm level. Despite the fact that theoretical models often yield outcomes in which either all producers or none are integrated (e.g. Arrow [1975]; Green [1986]), the Table shows that most markets in the sample had an intermediate structure, with both integrated and non-integrated firms.

III(ii). *Explanatory variables*

The analysis assumes that producers were observed in long-run equilibrium; firms were integrated in 1980 if integration was optimal, given characteristics of the product markets and the individual firm.

The explanatory variables reflect conditions observed during the 1970s. Engineering cost estimates, which were used to construct many of the explanatory variables, were taken from the 1976 issue of SRI's *Process Economics Program Yearbook*, which pertains to plants built in the mid-1970s. Historical output data were collected for both upstream and downstream products over the eleven year period from 1970 through 1980. The cost and demand conditions observed for the 1970s are assumed to be similar to those in effect in 1980 or any prior period when integration decisions were actually made.[13]

III(ii)a. *Factors implied by the transactions cost/asset specificity theory*

To test the three hypotheses derived in Section II from the transactions cost theory, measures of supplier concentration, asset specificity, and relative input cost are required.

A measure of supplier concentration is required to test hypothesis (H1), which predicts a higher likelihood of integration into upstream markets with few suppliers. The following measure was computed:

$$CONC = \text{reciprocal of the number of upstream suppliers at the end of 1980.}$$

If all upstream producers are of equal size, $CONC$ is identical to the

[13] Firms that entered during the 1960s, the period of greatest entry, experienced cost and market conditions roughly comparable to those in the 1970s. (Oil price shocks in the 1970s did, however, lead to greater cost and demand fluctuations.) Given the periodic need to replace, scrap or update plants, early entrants would typically have re-evaluated their integration choices during the 1970s.

Herfindahl index of seller concentration, except that the firm under consideration is excluded.[14]

Hypothesis (H2) implies that the incentives for backward integration increase with the degree of downstream "asset specificity". Two complementary measures of asset specificity were developed. The first measure is:

$$SUNK = \text{total fixed investment cost of the firm's downstream plant.}$$

This measure was computed by multiplying the firm's observed plant capacity in 1980 by an engineering estimate of total fixed investment per unit of capacity.[15]

Plants will normally be idled if they are unable to obtain supplies of the primary input. However, the extent to which plant assets were actually locked-in with a specific supplier is not known. Prior studies (e.g. Bradburd [1982]) offer evidence that supplier switching costs are often high, especially in the short run. For example, if all arms-length supplies of the input are committed to buyers through contracts, quick replacement of an existing supplier may not be possible.

A second measure of sunk costs that is more clearly transaction-specific relates to the type of transport facilities required. Most of the chemical inputs in the sample are liquids at room temperature (or after slight heating) which allows them to be pumped into railroad tank cars and transported at relatively low cost. The flexibility of railcar transport helps avoid problems of lock-in to a specific supplier. However, several upstream chemicals in the sample (ethylene, ethylene oxide, propylene, and chlorine) are gasses at room temperature. Large fixed investments in pipeline facilities are generally required to ship gasses between plants.[16] This investment is often highly

[14] Given that *CONC* is an imperfect proxy for the *ex ante* small numbers condition relevant to the transactions cost model, several related measures of upstream concentration were also tested. *CONC* is based on the total number of producers of the upstream input in 1980, including integrated firms. Inclusion of integrated producers in the count of potential suppliers is generally appropriate, since it is common for integrated firms to produce and sell a net surplus of the upstream product. Tests of an alternate measure of concentration, based only on the number of non-integrated suppliers, gave similar results to those reported below for *CONC*. Another problem with *CONC* is that the number of input producers observed in 1980 may not be indicative of the number anticipated at the time that the firm made its backward integration decision. To reflect the level of supplier concentration prior to the entry of many of the firms in the sample, an alternate measure of *CONC* was computed based on the number of input suppliers observed in 1965. The results for this measure were similar to those reported in Table II below. In general, the supplier concentration results proved robust to changes in definition and time period.

[15] For each product, the SRI *Process Economics Program Yearbook* reports an estimate of total fixed investment cost for a "typical" plant of given capacity. *SUNK* is based on the assumption that the required fixed investment per unit of capacity was constant over the range of plant sizes observed. Scale economies in investment are ignored, but the resulting errors are presumably small relative to variance in the magnitude of *SUNK* across observations in the sample.

[16] Chlorine is normally liquified and shipped in special containers.

specific to the plants that are interconnected. Thus, serious problems of lock-in may arise when firms purchase gaseous inputs from independent suppliers.[17]

The following zero/one dummy variable was used to capture this anticipated differential between gaseous and liquid inputs:

GAS = 1 if the upstream input is a gas.

Ten of the downstream products in the sample are based on gaseous inputs. One would expect a higher probability of backward integration by producers of these products, other conditions equal.[18]

Hypothesis H3 predicts that integration is more likely when the upstream input accounts for a large fraction of total cost. This hypothesis was tested using the measure:

IMP = cost of the upstream input, as a fraction of total production cost.

For each downstream product, the chemical input selected for analysis is the one that accounted for the largest fraction of total cost. This fraction varies across the sample, from a minimum of 31% (caprolactam) to nearly 100% (ethylene glycol, propylene glycol and phenol). Hypothesis (H3) implies that the probability of integration should increase with IMP.

III(ii)b. *Factors implied by the demand variability theories*

According to hypothesis (H5), derived from the Carlton model, backward integration is more likely when the firm's input requirements account for a large fraction of upstream industry output. This was tested using the measure:

$SHARE$ = firm's estimated consumption of the input, as a fraction of the total quantity produced by the upstream industry.[19]

The Carlton model implies that integration should be positively related to $SHARE$. On average, a given firm in the sample consumed about 5% of the

[17] The degree of lock-in derived from pipeline investments also depends on the location of the plants. Many chemical plants are concentrated along the Texas and Louisiana Gulf Coast. In this region, pipeline interconnections are common, and the existence of these interconnections facilitates possible recontracting with new suppliers. Logit equations that included a separate GAS dummy for Gulf Coast plants revealed that such plants were less likely to be integrated than plants located in other regions.

[18] Of the producers in the sample that used gaseous inputs, 55% were backward integrated at the plant level (65% at the firm level). Of the producers using non-gaseous inputs, 31% were integrated at the plant level (47% at the firm level).

[19] $SHARE$ was computed by multiplying (a) the firm's share of downstream industry capacity, by (b) downstream industry output in 1980 and (c) the amount of upstream input required per unit output, and then dividing by the total industry output of the upstream product in 1980. All measures pertain to the US market.

upstream industry's output. The sample contains only a few observations with large values of *SHARE*.

Measures of demand variability are required to test hypotheses (H4), (H6) and (H7). Such measures were computed for both the upstream and downstream markets, based on the annual industry output of each chemical over the 1970–80 period, measured in pounds. Upstream variability was decomposed into two components: (1) variability that was *independent* of fluctuations in downstream demand, and (2) variability that was *correlated* with downstream demand fluctuations.

For each observation in the sample, the variability measures were derived as follows. For the upstream product, the trend rate of output growth was removed by regressing total industry output, Q_{it}, on time and time-squared, i.e.

$$(1) \qquad \log Q_{it} = c + \beta_1 t + \beta_2 t^2 + \varepsilon_{it},$$

where t is an integer increasing in each year. An identical regression was run based on industry output of the downstream product. The measure, *UPVAR*, equals the sum of squared residuals from the upstream product regression. Similarly, *DNVAR* equals the sum of squared residuals from the downstream product regression.

For the upstream market, the amount of residual variance independent of fluctuations in downstream output was obtained by running the expanded regression:

$$(2) \qquad \log Q_{it} = c + \gamma_1 t + \gamma_2 t^2 + \gamma_3 \log Q_{jt} + \varepsilon_{it},$$

where Q_{it} represents total industry output of the upstream product, and Q_{jt} represents total industry output of the downstream product. The sum of squared residuals from this regression, designated *UPVAR'*, gives the variance of the upstream market output that was *independent* of fluctuations in the firm's downstream market. The component of upstream variability that was *correlated* with downstream fluctuations, *UPVAR''*, was obtained by subtracting *UPVAR'* from *UPVAR*. On average across the sample, about 58% of the upstream residual variance was correlated with the downstream product, and 42% was independent.

Hypotheses (H4), (H6) and (H7) imply the following connections between these demand variability measures and the probability of integration: (H4) implies a positive relation between integration and *UPVAR'*; (H6) implies a negative relation between integration and *UPVR''*; (H7) implies a negative relation between integration and *DNVAR*.

IV. EMPIRICAL FINDINGS

Table II reports the empirical results. The first two equations in the Table take plant-level integration as the dependent variable. The second two

TABLE II
LOGIT ANALYSIS OF BACKWARD INTEGRATION*

	Hypothesis and sign	1 Plant-level integration	2 Plant-level integration	3 Firm-level integration	4 Firm-level integration
constant	—	−5.8‡	−6.9‡	−5.3‡	−5.5‡
		(−4.4)	(−4.9)	(−4.2)	(−4.3)
CONC	H1 (+)	4.2	1.4	4.6†	3.7
		(1.9)	(0.6)	(2.0)	(1.5)
SUNK	H2 (+)	2.9	5.7†	5.8†	6.9†
		(1.2)	(2.1)	(2.2)	(2.4)
GAS	H2 (+)	3.0‡	2.1‡	2.2‡	1.9‡
		(5.2)	(3.6)	(4.1)	(3.2)
IMP	H3 (+)	3.7‡	6.2‡	3.3‡	4.0‡
		(3.0)	(4.0)	(3.1)	(3.3)
SHARE	H4 (+)	0.7	−2.1	1.2	0.2
		(0.2)	(−0.6)	(0.4)	(0.1)
UPVAR	—	16.7‡		14.7‡	
		(3.4)		(3.0)	
UPVAR′	H5 (+)		28.2‡		18.4‡
			(4.2)		(3.1)
UPVAR″	H6 (−)		2.1		9.8
			(0.3)		(1.6)
DNVAR	H7 (−)	−2.3	−1.9	1.5	1.8
		(−0.8)	(−0.6)	(0.6)	(0.7)
Log likelihood		−114.23	−108.41	−123.48	−122.70
Mean of dep. variable		0.389	0.389	0.532	0.532
Pct. predicted correctly		73.9%	74.9%	68.5%	69.0%
Number of observations		203	203	203	203

* Dependent variable denotes existence of backward integration at the plant or firm level, as discussed in text. Numbers in parentheses are asymptotic t-statistics.
‡ Significant at the 0.01 level, one-tailed test.
† Significant at the 0.05 level, one-tailed test.

equations are based on the firm-level measure. The results are similar for both pairs of logit equations.

The *CONC* coefficients appear with the expected positive sign but are statistically insignificant in all but equation (3). Thus, hypothesis (H1), which predicts a tendency for firms to backward integrate into markets with few suppliers, is not strongly supported. One possibility is that the sample does not contain a sufficient number of observations with high upstream concentration to strongly reject the null hypothesis. Alternatively, concentration may reflect production scale economies, which may render backward integration unattractive unless the firm has substantial requirements for the input. Several of the prior studies cited in Section II have found evidence consistent with hypothesis (H1).

The results provide stronger support for hypothesis (H2), that firms integrate to avoid problems of lock-in that may arise from large sunk investments. *GAS* is positive and highly significant in all of the logit equations; *SUNK* is significant in all but equation (1). Thus, the probability of integration was positively related to the total plant investment cost and the potential need to invest in input pipelines.

The positive coefficients for *IMP*, which are highly significant, offer support for hypothesis (H3). The larger the fraction of total cost represented by the input, the higher the probability of backward integration.

Of the demand variability hypotheses, only (H4), derived from the Carlton model, receives strong statistical support. The *UPVAR′* coefficient is positive as predicted and highly significant. This implies that firms integrated backward when they encountered substantial variability in the input market that was uncorrelated with fluctuations in their own downstream market.

The results fail, however, to support hypothesis (H5), which is a less central prediction of the Carlton model. The *SHARE* coefficient is not significant in any of the equations; thus, there is no evidence that firms were more likely to integrate when they accounted for a large share of total demand for the input. The negative result may be due to insufficient variation in the data sample. Only ten firms in the sample consumed more than 20% of total US production of the input required. Alternatively, the negative result may reflect the fact that demand is correlated across firms selling in the same downstream market. If large and small firms within the same downstream market have similar fluctuations in their input demand, this will attenuate the risk pooling benefits available to small buyers of the input, and integration choices may not differ by size of firm.

The measures *UPVAR″* and *DNVAR* are also insignificant, indicating lack of support for hypotheses (H6) and (H7). *UPVAR″*, the degree of variability in the input market that was correlated with the firm's downstream market, appears to have had no influence on integration decisions. Similarly, volatility in the firm's downstream market, as indicated by *DNVAR*, appears to have had little influence on integration decisions. The lack of significance for these two measures contrasts with the strong effect shown for *UPVAR′*. Firms appear to have integrated backward in response to volatility in the input market only when it arose from sources independent of their own downstream demand.

V. SUMMARY AND CONCLUSIONS

The results of this study indicate that both transactions costs and demand variability can create incentives for vertical integration. In terms of the seven hypotheses developed in Section II, the empirical tests strongly support hypotheses (H2), (H3) and (H4).

With respect to transactions costs, the results imply that firms integrated to avoid bargaining problems arising from *ex post* lock-in. The likelihood of integration increased with asset specificity, measured as the investment cost of plant and the potential need for inter-plant pipelines. These findings on sunk costs are consistent with prior empirical studies.

With respect to demand variability incentives, the results offer support for the Carlton [1979] model, but not for any of the other models considered. Firms appear to have integrated backward to avoid variability in the input market that was independent of fluctuations in their downstream market. This is consistent with the main prediction of the Carlton model, although not with Perry [1984]. The analysis fails to confirm Harrigan's [1983] hypothesis that backward integration is discouraged by volatility in downstream demand.[20] Similarly, there is no support for the Blair and Kaserman [1983] risk aversion motive for avoidance of integration.

While the results suggest support for the Carlton model, the question remains as to why firms integrate rather than enter into long-term contracts for the input. Such contracts are not distinguished from vertical integration in Carlton's model; either alternative provides a solution to the costs associated with demand variability. Thus, some reference to the transactions cost approach is necessary to predict which alternative is likely to be most viable. Firms will opt for integration if it is difficult to write contracts that adequately cover future contingencies. In this context it is interesting that integration was stimulated only by those fluctuations in the input market that were independent of the firm's own downstream demand. This suggests that it is difficult to specify contracts that fully account for contingencies related to the demands of other buyers; whereas contingencies associated with the buyer's own demand are easier to incorporate, (e.g. through minimum and maximum quantity guarantees, price schedules, and the like). Moreover, given the limited duration of most chemical supply contracts and the need for periodic renegotiation of terms, buyers with relatively stable input requirements may be reluctant to enter into supply agreements given the likelihood that renegotiation will be necessary during periods when other buyers are facing peak demand.

An additional finding, consistent with both the transactions cost model and the Carlton model, is that firms tended to integrate when the input accounted for a large fraction of total cost. Both models imply that a price premium may be charged by input suppliers; the premium will be greater in absolute terms when the input is a substantial cost component. This in turn justifies greater investment in fixed plant facilities for production of the input, even if independent suppliers enjoy lower unit investment costs (e.g. due to economies of scale). Moreover, if management is risk averse to paying large sums for inputs under conditions of supplier "hold up" or peak demand, integration may appear attractive even if the firm suffers from high variable cost as an input producer.

While the results of this study are generally consistent with the transactions

[20] Harrigan considered volatility as a broader concept than the simple output variability measure tested here. Conceivably, the hypothesis may hold up more strongly with respect to other types of volatility (e.g. technological uncertainty) or in other industry environments.

cost and Carlton models, many caveats apply. Two of the hypotheses implied by these models fail to receive empirical support. This is probably due to limitations of the data sample, but it could indicate that the other, more supportive findings are spurious, particularly in the case of the Carlton model which has not been verified in prior empirical work. The explanatory variables are imperfect measures, and omitted variables may bias the results. It is also possible that findings are specific to the chemical processing sector, and care should be taken in generalizing the results.

MARVIN B. LIEBERMAN,
Anderson Graduate School of Management,
UCLA,
Los Angeles, CA 90024-1481,
USA.

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