UNIVERSITY OF CALIFORNIA, BERKELEY

Department of Economics

Berkeley, California 94720

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ESTIMATION OF THE PROBABILITY OF ACQUISITION IN AN EQUILIBRIUM SETTING

Bronwyn H. Hall

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ABSTRACT

Recent work by Auerbach and Reishus (1987) and Hall (1987) has made use of logit models of individual choice behavior to estimate econometrically the probability that one firm will acquire another one. This paper considers more carefully the theoretical underpinnings of such econometric models and shows that it is not possible to derive the simple logit models used in previous work rigorously when the market consists of a finite number of differentiated buyers and sellers. This feature characterizes the market for corporate assets strongly, and may be important even in settings where logit models of choice have been previously applied, such as the market for single family houses.

I offer two partial solutions to this theoretical problem, one which implies estimation from the perspective of the acquiring firms, and one which implies estimation from the perspective of the selling firms. I then implement these solutions using a sample of approximately 300 corporate acquisitions in the United States manufacturing sector which took place between 1976 and 1985. The conclusion is that although the sellers' model is easier to justify than the buyers' model, estimates from the two models appear consistent with eachother, and both sets of estimates confirm the results in Hall (1987), that the gain from an acquisition is positively related to the acquiror's size, the acquiree's R&D intensity, and inversely related to the distance between the two firms in size-R&D space. A more complex nested logit model where firms are grouped within industry fails to overturn this result and does not appear to be preferred over the simpler models.

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ESTIMATION OF THE PROBABILITY OF ACQUISITION IN AN EQUILIBRIUM SETTING

Bronwyn H. Hall[1]

1. Introduction

Recent work by Auerbach and Reishus (1987) and Hall (1987) has made use of logit models of individual choice behavior to estimate econometrically the probability that one firm will acquire another one. The motivation for the use of such a model is its previous success in describing markets where products are differentiated but may be described by a vector of characteristics, typically of much lower order than the number of products available, as well as its tractability for estimation using relatively large datasets. See Manski and McFadden (1981) and Train (1986) for references to much of this work. In the case of mergers and acquisitions, the underlying idea is that each potential acquisition (a firm) is a package sale (in the large, notwithstanding a limited ability to break up a firm into divisions, etc.) embodying a collection of varying amounts of different assets,

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1. I am particularily grateful to Takeshi Amemiya and Timothy Bresnahan for discussions and suggestions which have greatly improved this paper, and to Ariel Pakes, whose comment on my predecessor paper on this topic motivated some of the discussion here. Some of this work was done while I was a John M. Olin graduate research fellow, and I thank this foundation for their support. The data preparation effort was partially supported by a National Science Foundation Grant (PRA 81-08635) and by the National Bureau of Economic Research.

which are priced in combination by the market for corporate control. Models of choice behavior when confronted with a finite set of such differentiated products might therefore allow us to estimate the "demand" for these assets.

Two problems with the direct transfer of this methodology from consumer choice to mergers and acquisitions confront one immediately: the first turns out to be purely econometric and can be solved in more than way. This is the problem of the large choice set available to any potential acquirer or acquiree. In Hall (1987) I used the simplest solution to the problem, which is to sample from the choice sets available when constructing the likelihood function. An alternative is to use moments of the variables describing the choice set up to some order to characterize their distribution; this was the method used by Auerbach and Reishus. Either method will yield (approximately) consistent estimates (McFadden 1978).[2]

More difficult to solve is the problem of what to do about prices in these models. Conventional econometric models of the market for differentiated products take prices as exogenous, whereas here we suspect that the prices are being influenced by the buyers in the market. In fact, the usual proofs of equilibrium in markets with nonconvex (indivisible) goods rely on assuming a continuum of consumers,

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2. McFadden shows that the first method (sampling the alternatives) yields consistent estimates of the parameters under normal regularity conditions (Theorem 2, 1978). The second method will yield consistent estimates only if the order of the moments used to characterize the distribution of the X's is increased along with the sample size.

which is clearly not an attractive assumption here (Mas-Colell 1977). In addition, there is a considerable body of empirical evidence (see Jensen and Ruback 1983) showing that prices tend to change by significant amounts when transactions in this market are announced.

The problem with using the individual choice model approach on data from the merger market can be seen in this way: consider a consumer confronted with a set of alternative choices C, each with a price p_i and characteristics X_i. He will choose from the set that alternative which has the highest surplus to him, where the surplus is defined as his reservation price for that bundle of characteristics less the price p_i. The probability that a given choice is made will depend on the characteristics of the choices, the utility function of the consumer, and the prices. Econometric estimation of the probabilities allows us to derive the "demand" for the underlying characteristics embodied in the goods. This is how the results of estimating models of demand for differentiated products are commonly interpreted in the literature.

However, note that an unstated assumption about the nature of the market has been made in identifying these probability estimates as "demand" functions: the existence of competing buyers of the goods in question has been ignored. This is acceptable if the goods are automobiles of a certain model, or appliances, but less acceptable for unique goods such as residential housing or merger candidates. In the former case, identification of the demand curve has been achieved by essentially assuming an infinite supply of the particular good at the price in question. This assumption is unacceptable in the market for corporate assets. For this market, the probability that one firm will acquire another at a given set of prices depends not only on that firm's desire to make the acquisition, but also on the existence of other firms in the market which desire the same acquisition at those prices. This will be made more precise in the body of the paper.

Fortunately, the fact that demand is not easily distinguished from supply in the acquisition market does not prevent me from estimating parameters of interest using data on transactions which actually occur. Under the assumption of efficient markets, corporate assets will move to their highest valued use, so that the motivation for transactions in this market is the total surplus realized by both parties when one firm buys another. The price at which the transaction takes place merely serves to allocate the rents between the two parties. This implies that if I can estimate the probability of acquisition as a function of the total gain from the transaction, I can characterize the sources of these gains from efficiency considerations rather than estimating demand functions per se.

The purpose of the present paper is to consider more carefully several of the issues raised by using this kind of model to estimate acquisition probabilities. First I show more explicitly why a simple model with differentiated buyers and sellers does not lead to tractable estimating equations. Then I consider how this model must be modified in order to lead to the kinds of equations estimated by Auerbach and Reishus and myself. The required modifications are not unreasonable, but it is difficult to see how to test them at the present time.

I then use these modified models to estimate the probability that one firm will acquire another both from the perspective of the seller and then from the perspective of the buyer. Since the purpose of this paper is to establish a useful methodology for dealing with this kind of data, I confine my specifications to a limited number of variables and focus on the internal consistency of the models from the two different perspectives. It turns out that these two perspectives give similar results, which is a kind of specification test of the underlying framework. In addition, they allow me to say something about the correlation structure of the unobservables in the model.

Finally, I present the results of estimation with a more complicated nested logit model where the possible acquisitions (or acquirers) are grouped by industry, on the grounds that potential acquiring firms, for example, are more likely to look for acquisitions in a particular industry, and hence to value all of them (separately) more highly if they value one more highly. This turns out to be undetectable in these data, which is a somewhat surprising result.

2. Equilibrium in the Market for Acquisitions

The market for corporate assets is no different from any other economic market: the transactions which we observe represent the intersection of the supply of such assets and the demand for them. There is a large literature on the econometric estimation of such supply and demand functions in the differentiated product setting (the hedonics model) which I have chosen to ignore for the moment, since all the many problems of identification raised by Sattinger (1982), Epple (1987), and others seem insuperable here, where the agents on both sides of the market have considerable market power. Instead, I view the problem initially as a (monogamous) marriage market, with unique gains accruing from each transaction, but with each buyer and seller engaging in one and only one transaction (the transaction may be simply doing nothing). The estimation strategy will characterize the gains from the acquisitions which take place, but will not use prices to do so: the function of prices in this model is merely to allocate the gains (rents) between the buyers and sellers.

My starting point is a model due to Koopmans and Beckmann (1957)[3] which, although not precisely applicable to the market here where buyers and sellers may be the same group of firms, shows that an efficient allocation which can be supported by prices does exist in this type of market. This model also helps me to specify the conditions which determine this allocation without having the prices enter explicitly.

Consider the following marketplace: there exist one each of N differentiated goods, each with its own unique characteristics. There are also N consumers with differing tastes, each of whom can assign a value (reservation price) to each of the goods, i.e. good i is worth V_{ij} to person j. The consumers also have a reserve value, the value of purchasing none of the goods, which we take without loss of generality to be zero. Note that I have assumed at the outset that no consumer faces a budget constraint, since the set of goods available to each of the consumers is identical.[4] The problem to be solved is this: does

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3. I am grateful to Jim Heckman for supplying me with this reference.

4. The assumption of no budget constraint guarantees that the consumer is able to make purchases he would like to make at the existing price and his reservation price V_{ij}. It corresponds roughly to the current situation in the merger market, where junk bond financing is used for deals which would not otherwise be affordable to the acquiring firms. It amounts to an assumption that the firm can raise capital at a cost no higher than the increase in equity implied by the acquisition in order to perform the acquisition. Any deviation of this cost from the rate of return required by the market is incorporated into the reservation price itself.

there exist a set of prices for these goods such that the market clears, that is, one and only one consumer desires to purchase each good, and all goods are claimed?[5] Although this situation does not fit the conventional Walrasian model due to the non-convex consumption set, the answer to this question is yes; this is the main result of the Koopmans-Beckmann paper.

The problem considered by Koopmans and Beckmann is slightly different: it is the problem of assigning each of N plants to one of N locations, one plant per location, where there is a unique rent to be obtained from each assignment. They show first that a solution to the social problem of maximizing the surplus (sum of the rents) can be obtained by linear programming methods, and secondly, that this solution can be sustained by a system of rentals on all plants and locations. If the owner of each plant knows only the rents at all possible locations and the value of the location to him, this information is sufficent to establish and sustain the equilbrium, which is also a social optimum. Conversely, if the owner of each location knows the rent for each plant and its value to him, this is also sufficient to sustain the equilibrium. Because of the finiteness and indivisibility of the problem, the set of prices which will sustain the equilibrium is not unique, but consists of a set of intervals.

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5. The assumption that all goods are claimed is made for convenience. It is obviously violated in the market for acquisitions. By noting that the set of goods and the set of consumers are the same set in the merger market, it is possible to fix things up by allowing firms to purchase themselves.

In terms of the problem at hand, V_{ij} denotes the profitability (value) of firm i's assets when they are located in firm j, while p_i is the "rent" charged by firm i (its price). $V_{ij}-p_i$ then becomes the surplus obtained by firm (location) j. The V_{ij}s form the matrix of payoffs to different combinations of firms. Because both sides of the market consist of the same firms, the option of no sale or acquisition corresponds to a match on the diagonal. All the V_{ij}s are assumed to be strictly positive (remember that these are the gross value of firm i's assets to firm j). If I index the firms so that the optimal allocation has firm j making acquisition i, The Koopmans-Beckmann paper shows that there exists a system of nonnegative rentals, $p_i \geq 0$, $i = 1, \ldots, N$ and $q_j \geq 0$, $j = 1, \ldots, N$, such that

(1) $$V_{ij} = p_i + q_j \qquad i = 1, \ldots, N$$

and

(2) $$V_{kj} \leq p_k + q_j \qquad k = 1, \ldots, N$$
$$V_{im} \leq p_i + q_m \qquad m = 1, \ldots, N$$

The first equation gives the rent to the acquiring firm: it is the surplus remaining after paying for the acquisition, $V_{ij}-p_i$. The second equation can be rewritten as a statement that firm j prefers acquisition i to all other acquisitions:

(3) $$V_{ij}-p_i \geq V_{kj} - p_k \qquad k = 1, \ldots, N$$

The third is a symmetric equilibrium condition which guarantees that no other firm will wish to make the acquisition; it too can be rewritten:

$$(4) \qquad q_m \geq V_{im} - p_i \qquad\qquad m = 1, \ldots, N$$

which states that no other firm m can obtain a surplus by buying firm i which is larger than that obtained from the transaction which m actually makes (q_m).

Although the Koopmans-Beckmann results guarantee an equilibrium supported by prices in this market (under the somewhat restrictive assumption that a firm can buy one and only one firm per period), the interpretation of the equilbrium need to be examined somewhat more carefully in my particular case where buyers and sellers coincide. Note that there is no guarantee that the solution (optimal allocation) will match firm i to firm j and firm j to firm i, as would be required if a merger were to take place. We can distinguish three cases: The simplest case is where firm i wishes to buy firm i; this would happen when the equilibrium price for firm i's assets is at least as large as all the off-diagonal elements involving firm i or when the value of the assets alone is at least as large as their value when combined with the other firms. The case of a pair of firms each of which wish to buy eachother is the simplest merger or acquisition case, but cannot be guaranteed.[6] The third possbility is that a solution emerges where firm 1 wishes to buy firm 2, firm 2 wishes to buy firm 3, and firm 3 wishes to buy firm 1. In this case, all three firms must merge, and similarily for larger groups of interconnections. Lack of observation

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6. One can define a new problem where the permutation matrix is symmetric in order to guarantee this result, but it is possible to show that the optimal allocations for such a problem cannot be supported by prices some of the time. A simple 3 by 3 counterexample suffices for this (see Appendix 1).

of large amounts of this phenomenon in the merger market implies that the V_{ij}s are highly variable across different js and that high V_{ij} tends to imply high V_{ji} and vice versa.

Setting this last problem aside as relatively unimportant in practice, I can now make the following observation: if I assume that the market for corporate assets is efficient and clears, that news arrives every period about the value of these assets in different configurations thus changing the optimal allocation, that these bundles of assets are generally indivisible, the Koopmans-Beckmann model tells me that there do exist prices on one side of the market which guarantee the efficient allocation, but that these prices are fully endogenous to the underlying valuations of the assets.

To see this, assume (for notational convenience, without loss of generality) that the efficient allocation is one where buyer i claims seller i, for all i=1,,,N. We can eliminate the rents $\{q_j\}$ accruing to the buyers by using (1) to substitute them out with $V_{ii}-p_i$ everywhere that they appear. Then the two equations (2) become

$$(5) \qquad V_{ii}-p_i \geq V_{ki}-p_k \qquad k = 1,,,N$$

$$(6) \qquad V_{mm}-p_m \geq V_{im}-p_i \qquad m = 1,,,N$$

To eliminate prices from these equations, note that the equations hold when the index k is equal to m, so that the first equation becomes $V_{ii}-p_i \geq V_{mi}-p_m$, which when added to the second equation gives

$$(7) \qquad V_{ii}+V_{mm} \geq V_{im}+V_{mi} \qquad \forall\ m,i$$

This just says that i and m achieve a higher value with the allocation which they have than in one in which they are interchanged. Similarily, three such equations can be added together to obtain

$$(8) \qquad V_{ii}+V_{mm}+V_{kk} \geq V_{im}+V_{mk}+V_{ki} \qquad \forall\ m,i,k$$

This equation states that no three buyers can get together and achieve a higher total gain by switching allocations. We can proceed in this way until we have used all N of the buyers:

$$(9) \qquad \sum_{i=1}^{N} V_{ii} \geq \sum_{i=1}^{N} V_{ij_i} \qquad \forall\ \{j_i\}$$

where $\{j_i\}$ is a permutation of (1,2,,,,N). Now note that equations (10) and (11) are just special cases of (12) where some of the buyers do not switch their allocations, so the total number of such inequalities is N!, the number of permutations possible. But this just defines the socially optimal allocation of the N sellers to the N buyers by enumeration; it is the solution to the problem

$$(13) \qquad \underset{\{j_i\}}{\text{Max}} \sum_{i=1}^{N} V_{ij_i}$$

Now consider the problem of writing down the probability that a particular acquisition will take place in this market. These equations make it clear that the probability that firm j acquires firm i depends not only on the value of all possible transactions into which j and i might have entered, but on the values of the transactions made by the other firms in the market. To understand what this means for estimation, consider the following simple example: there are 3 potential acquirers and 3 acquisition candidates. We can write the matrix of payoffs from possible transactions thus:

		Buyers 1	2	3
	1	V_{11}	V_{12}	V_{13}
Sellers	2	V_{21}	V_{22}	V_{23}
	3	V_{31}	V_{32}	V_{33}

The probability that we will observe the event 1 buys 1 can be written in the following way:

$$
\begin{aligned}
(14) \qquad \Pr(1\text{-}1) &= \Pr(1\text{-}1,\ 2\text{-}2,\ 3\text{-}3) + \Pr(1\text{-}1,\ 2\text{-}3,\ 3\text{-}2) \\
&= \Pr(V_{11} + V_{22} - (V_{21} + V_{12}) > 0, \\
&\qquad V_{11} + V_{33} - (V_{31} + V_{13}) > 0, \\
&\qquad V_{22} + V_{33} - (V_{32} + V_{23}) > 0, \\
&\qquad V_{11} + V_{22} + V_{33} - (V_{31} + V_{12} + V_{23}) > 0, \\
&\qquad V_{11} + V_{22} + V_{33} - (V_{13} + V_{21} + V_{32}) > 0) \\
&+ \Pr(V_{11} + V_{23} - (V_{21} + V_{13}) > 0, \\
&\qquad V_{11} + V_{32} - (V_{31} + V_{12}) > 0, \\
&\qquad V_{23} + V_{32} - (V_{22} + V_{33}) > 0, \\
&\qquad V_{11} + V_{23} + V_{32} - (V_{31} + V_{13} + V_{22}) > 0, \\
&\qquad V_{11} + V_{23} + V_{32} - (V_{21} + V_{33} + V_{12}) > 0)
\end{aligned}
$$

This probability is a function of all the values in the payoff matrix and cannot easily be factored, even if the V_{ij}s are independent random variables. In general, the number of inequalities in any particular probability will be N!-1, which makes estimation impossible for any reasonably sized dataset.

Adding prices does not really help, because of their endogeneity, although it does eliminate some of the V_{ij}s from equation (14). Given a set of prices for the acquisitions p_1, p_2, and p_3, the probability of the observed transaction (1 buys 1, 2 buys 2, 3 buys 3) can be written as

$$(15)\qquad \Pr(1\text{-}1,2\text{-}2,3\text{-}3) = \Pr(V_{11}-p_1>V_{21}-p_2,\ V_{11}-p_1>V_{31}-p_3,\ V_{22}-p_2>V_{12}-p_1,\ V_{22}-p_2>V_{32}-p_3,\ V_{33}-p_3>V_{13}-p_1,\ V_{33}-p_3>V_{23}-p_2)$$

Only under the following rather stringent conditions would it be possible to estimate the model by focusing only on the possible acquisitions which a firm might make: 1) the prices p_i are exogenous or perhaps predetermined, and 2) the random variables V_{ij} are independent across columns, although they may be dependent within a column. These conditions would allow me to factor the probability in such a way that I could use only information on other possible acquisitions for each firm and obtain consistent estimates of the parameters of V_{ij}:

$$(16)\qquad \Pr(1\text{-}1,2\text{-}2,3\text{-}3) = \Pr(V_{11}-p_1>V_{21}-p_2,\ V_{11}-p_1>V_{31}-p_3) \cdot \Pr(V_{22}-p_2>V_{12}-p_1,\ V_{22}-p_2>V_{32}-p_3) \cdot \Pr(V_{33}-p_3>V_{13}-p_1,\ V_{33}-p_3>V_{23}-p_2)$$

Although assumption (2) may be somewhat reasonable (it says that the value buyer 1 attaches to an acquisition is independent of the value buyer 2 places on the same acquisition after controlling for measured characteristics), assumption (1) is very unattractive. In reality, the p_i's are functions of all the valuables placed on i by all the other potential buyers, as I emphasized in the introduction and therefore there is no reason to think that they can be treated as exogenous like this. However, in spite of these difficulties, this model is one possible justification for the procedure of estimating the probability of an acquisition by focusing on the alternatives available to the buyer. In the empirical work I find evidence that the answers obtained with a model of this type are not that different from those obtained using the model of the next section and that at least assumption (2) is approximately true in the data.

3. Equilibrium when a firm can make more than one acquisition

The preceding section concluded that a model with a finite set of differentiated buying and selling firms would not yield tractable estimating equations without strong econometric assumptions. Now I make a slight change in the assumptions about the way the merger market works which makes estimation somewhat easier and brings things closer to the real world. I assume that a consumer (firm) can buy more than one of the goods (other firms). In this case, it is easy to exhibit a set of prices which will clear the market and also easy to eliminate these prices from the model: a price which is slightly higher than the second highest value will give the good to the highest valuer. To show this, for each good, i, I order the valuations of that good by each consumer and obtain the order statistics $(V_{i(1)}, V_{i(2)}, \ldots, V_{i(M-1)}, V_{i(M)})$ such that

$$V_{i(1)} < V_{i(2)} < \ldots\ldots < V_{i(M-1)} < V_{i(M)} \tag{17}$$

The equilibrium price vector $p^* = (p_1^* \ldots\ldots p_N^*)$ will be defined by

$$p_i^* \in (V_{i(M-1)}, V_{i(M)}) \tag{18}$$

Then it is easy to show that $\forall$ i=1, ... ,N:

$$V_{i(M)} - p_i^* = \max_j (V_{ij} - p_i^*) \tag{19}$$

$$V_{i(M)} - p_i^* > 0.$$

As Pakes (1987) has pointed out, these equilbrium conditions can be used to estimate the parameters of V_{ij} in a straightforward way. At any set of prices p_i, we have the following:

$$\Pr(i \text{ is bought by } j) = \Pr(V_{ij} \geq V_{im} \; \forall \; m, \; V_{ij} > p_i) \tag{20}$$

which depends only on the value attached to the acquisition of i by possible purchasers. An advantage of this model is that price drops out of the first equation in (19) so that we need not have data on it if we wish to estimate conditional on an acquisition being made.

In applying this model to the merger market, I note that although it is true that most firms make only one acquisition per year, some firms make several. The typical case of one or fewer acquisitions is easily obtained if the value of an acquisition is very idiosyncratic to a firm. The second implication of this model is that any set of prices such that price lies between the highest valuer of control of the asset and the second highest valuer will clear the market.

How is the price at which trade actually takes place established? Now the problem becomes a bargaining problem: who gets the surplus, the buyer or seller? In general this would depend on the market power and/or threat points of each, but in this case, there are other actors in the market for the assets of this firm. In a conventional bargaining problem, the buyer is a monopsonist and the seller is a monopolist; in this case, because anyone can buy shares in either firm, the surplus ought in principle to fall to the first few traders who identify the merger possibility (assuming that the disequilibrium arises for information reasons). In fact, it appears that trades take place at prices close to $V_{i(M)}$, the first best use, or at least well above the pre-merger value of the firm.

What this implies about the valuation equation I should use in estimating a merger choice model depends on the assumptions I make about the way information about potential acquisition possibilities is diffused in the market. If I assume that traders as a group are somewhat myopic, that is, they cannot tell that a better use exists for a target's assets until some firm discovers this fact and makes a takeover bid, then I can interpret the pre-offer price at which the target firm's stock trades as the value of the firm's assets in their existing use, (but not necessarily the second best price). If they then become fully informed, a rational bidding firm will offer the lowest price at which no other firm will be interested in the acquisition, that is the price at which the takeover takes place will be the value of the target firm in its second best use. If this were significantly less than the first best price, we would expect a positive surprise in the acquiring firm's stock due to the surplus thereby captured. The fact that in most cases we do not see such a surprise suggests either that takeover activity by bidding firms is fully anticipated by the market, even though the market cannot identify the candidates perfectly, or that the gap between the first and second best price is quite small. This latter explanation seems quite plausible when considering tax-motivated mergers (but see Auerbach and Reishus (1985) and Gilson, Scholes, and Wolfson (1985) for evidence that these cannot be a very large share of merger activity) and acquisitions whose primary purpose is a restructuring of the target firm by selling off major portions. Such acquisitions do not depend on a particular synergistic relationship to generate surplus for those who identify them.

In spite of these difficulties with prices, the model outlined in this section is attractive for estimation of the gains from takeover, since it follows from a few simple assumptions about the nature of the market, and has the feature that price does not appear at all if we condition on the acquisitions which are made. Note that the assumption that firms can buy make more than one acquisition at a time is crucial, since assuming the contrary would just put us back in the model of Section 2, where a selling firm might not sell to the highest valuer if that valuer had a better deal available.

4. Econometric Estimation of Merger Models

In this section I consider the problem of estimating a model of acquisition probability in the absence of information on the prices of the assets being acquired. My approach here is motivated by the discussion in the earlier sections of this paper: the price at which an acquisition takes place is likely to be an endogenously determined division of the rents which accrue to a merger, and initially I would like to perform the estimation without attempting to model that division. This approach is especially attractive since I do not observe the rent division in the case of acquisitions which are not made. But note that the addition of a model of rent division or bargaining where the dependent variable is only partially observed is possible in this framework and might possibly provide more informative estimates.

The previous sections made it clear that, because of the market power of the participants in the merger market and the difficulties of solving prices out of the model, a model which allowed polygamy such as equation (20) was preferable for estimation since it allows estimation by focusing only on the alternatives available to the seller rather than those available to both buyer and seller. In fact, I show in this section that I can obtain consistent estimates for some of the parameters in the V_{ij} function using the model of Section 3. Note, however, that a key assumption of this model is that buyer j can buy as many firms as he wishes, and that the valuation he places on one of them is not affected by whether or not he acquires others.

I partition the valuation which firm j places on acquisition i in the following way:

$$(21) \qquad V_{ij} = f(X_i,X_j) + d(X_i) + \varepsilon_{ij}$$

where X_i and X_j are vectors of characteristics of the acquiring and acquired firms and ε_{ij} summarizes our inability to completely describe the firms, as well as our lack of knowledge of the valuation function. This way of writing V_{ij} makes interpretation of the model easier, since terms involving only i will drop out of the first inequality in equations (20). Given this form of V_{ij}, the probability that firm i will be acquired by firm j out of a set C of possible acquirers is

$$(22) \qquad P(V_{ij} \geq V_{im} \ \forall\ m \in C \text{ and } V_{ij} - p_i \geq 0) =$$
$$P(\varepsilon_{ij} - \varepsilon_{im} \geq f(X_i,X_m) - f(X_i,X_j) \ \forall\ m \in C,\ \varepsilon_{ij} \geq p_i - d(X_i) - f(X_i,X_j))$$

Now I must confront the specification of the price p_i which appears in equation (22). I assume for the moment that the price faced by all the firms in the market is a function of their characteristics and a disturbance which is independent of the disturbances in the V_{ij}s:

$$(23) \qquad p_i = h(X_i) + \varepsilon_i$$

As I show in Appendix 2, the assumption of independence of ε_i from the ε_{ij} imposes no restrictions on the model once I assume that the εs have an extreme value distribution. However, if ε_i is not independent, as seems likely, the interpretation of the coefficients in the $f(\cdot,\cdot)$ function will be affected, although the conditional probabilities will not be. With this definition of p_i, the expression for the probability that i is purchased by j in equation (22) becomes

$$(24) \qquad P(\varepsilon_{ij}-\varepsilon_{im} \geq f(X_i,X_m)-f(X_i,X_j)\ \forall\ m\in C,\ \varepsilon_{ij}-\varepsilon_i \geq h(X_i)-d(X_i)-f(X_i,X_j))$$

By placing a particular generalized extreme value (GEV) distribution on the ε's, I can derive acquisition probabilities using the methods of McFadden (1978). This is not a conventional choice model, however: if one wished to interpret it as the outcome of a maximization problem, this model describes a choice made by firm i of possible acquirers in which i maximizes not his own price, but the surplus received by his potential acquirers.

The GEV distribution I choose initially is the simplest which is consistent with the particular features of this problem:

$$(25) \qquad F(\varepsilon_i,\varepsilon_{im},\ m\in C) = \exp\left\{ -\left[e^{-\varepsilon_i} + \left(\sum_{m\in C} e^{-\varepsilon_{im}/\lambda}\right)^{\lambda} \right] \right\}$$

This distribution specifies that the unobserved part of the acquisition gains may be correlated ($\lambda<1$), that is, there may be some propensity to be acquired on the part of firm i which makes it more valuable to all acquirers if it is more valuable to one, but that there is also an independent disturbance affecting the probability that firm i will be acquired at all. That is, the independence of irrelevant alternatives (IIA) property holds for the potential acquirers, so that if one candidate disappears, the probability ratios of the remainder are unaffected, but this property does not hold between the option of not being acquired and being acquired: deleting one potential acquirer will generally increase the probability that no acquisition is made as well as increasing the ratio of that probability to the probability of any particular acquisition. These are familiar properties of the nested logit model, but it is nevertheless worthwhile to keep them in mind when considering the estimation results. Clearly this is the simplest possible structure I might estimate; an alternative which grouped possible acquisitions by industry might have more attractive IIA properties, since presumably two firms in the same industry would be more highly correlated than firms in vastly different industries.

Given the assumption of the distribution in (25), it is straightforward, but somewhat tedious, to show that the acquisition probabilities for firm i are the following:

$$(26)\qquad \text{Prob (i is acq. by some m, } m \in C \mid C) = I_i^{\lambda}/[\exp(-g(X_i))+I_i^{\lambda}]$$

$$\text{Prob (j buys i} \mid C, \text{i is acq.)} = \exp[f(X_i, X_j)/\lambda]/I_i$$

where

$$(27)\qquad I_i = \sum_{m \in C} \exp\left[f(X_i, X_m)/\lambda\right]$$

is the "inclusive value" of the acquisition alternatives available to firm i and

$$(28)\qquad g(X_i) = d(X_i) - h(X_i)$$

simplifies the notation in an obvious way. The usual factoring of a nested logit probability into a marginal probability and a conditional probability which does not depend on the additively separable terms in X_i obtains:

(29) Prob (j buys i|C)

$$= \text{Prob(j buys i}|\text{C,i is acq.)} \cdot \text{Prob(i is acq. by m, m}\in\text{C}|\text{C)}$$

$$= \frac{\exp[f(X_i,X_j)/\lambda]}{I_i} \cdot \frac{I_i^{\lambda}}{\exp[-g(X_i)]+I_i^{\lambda}}$$

This allows me to estimate some parameters of the model consistently by confining the estimation only to those firms which actually were acquired, for example. In particular, even if ε_i is not independent of the ε_{ij}s, the probability that j buys i conditional on i having been bought can be consistently estimated.

Before I present the results, there is one modification to the model of this section which is made for econometric reasons which needs to be justified: it is well-known that failure of the homoskedasticity assumption for the disturbances in qualitative dependent variable models leads to inconsistent estimates. Because of the large size range of the firms in my dataset, this failure is likely to occur if the model is specified in terms of the total valuation of the potential acquisitions, V_{ij}. To avoid this problem, I use a multiplicative form for the disturbances and specify the estimating equations in terms of the logarithms of the variables. This can be justified in this case since the logarithm is a monotonic transformation of the underlying variable, and hence the probabilities which I defined remain unchanged:

$$(30) \qquad V_{ij} \geq V_{im} \quad \text{iff} \quad \log V_{ij} \geq \log V_{im}$$

$$V_{ij} \geq p_i \quad \text{iff} \quad \log V_{ij} \geq \log p_i$$

The functions f and g are expressed as linear functions of the characteristics of the buying and selling firms, and of distance measures based on those characteristics.

Table 1 displays the results of estimating the model by conditional maximum likelihood estimation, the two-step consistent method, and maximum likelihood on the nested logit model. The two key characteristics of the firm are their size (log A, the logarithm of capital stock) and their (longrun) R&D intensity (K/A); see Hall (1987) for further details on the sample and variables. For the firm being acquired, these variables are the ones in $g(X_i)$. The model of the valuation function $f(X_i,X_j)$ is a simple log-linear model which includes the characteristics of the potential acquirers, and the absolute values of the difference between X_i and X_j as distance measures to capture the closeness of the firms to eachother; these variables were found to work somewhat better (in the sense of fit) than either squared distances or product variables. Included with the distance measures is a dummy variable which is equal to one if firm j and firm i are in the same two-digit industry and zero otherwise.

The first two columns of the table are estimated using the part of the sample which was acquired (or which made acquisitions), although of course the set of acquiring firms available include the whole sample. The first column shows estimates of the coefficients based on the probability of being acquired by the firm which actually acquired firm i conditional on seven firms drawn at random from the set of firms in existence that year (usually about 2000), while the second column shows the same estimates made with a subset of five firms out of the seven. As Hausman and McFadden (1984) have shown, a comparison of these two sets of estimates yields a test of the IIA assumption which was imposed on the acquisition alternatives. The test is accepted, with a χ^2=0.6.

This is a relatively weak test for the internal consistency of the model, which merely says that changing the number of alternatives sampled for estimation by a small amount does not change the estimates too much, suggesting that seven is perhaps an adequate number of alternatives; as a byproduct of the industry grouped estimation presented in the next section, I present evidence that the efficiency gain from increasing the number of alternatives to 50 from 7 (a gain of sevenfold) is only about thirty percent (based on a comparison of the standard errors). That is, increasing the number of choice alternatives from 7 to 50 is approximately as good as increasing the number of observations from 311 to around 400.

A more interesting test for the specification of the model is given by the estimates in the third column: here I treat the alternative of no sale on an equal basis with the other alternatives. That is, the model of equation (29) is estimated with λ set equal to one, so that there is no correlation across the disturbances for any of the alternatives. The sample of observed acquisitions has also been augmented with a set of possible acquisitions which did not take place.[7] Here a test of the equality of the five coefficients which are estimable in both columns fails (albeit weakly) with a $\chi^2(5)$ = 17.1.

----

7. Approximately 2000 such potential acquisitions were used out of a population which is 2^{2000} (since any firm can acquire any other firm in a given year). If the observations included are randomly sampled, as they were here, the inclusion of subset of the observations in the estimation affects only the estimated constant in the value function, which I have not reported (see Palepu 1986 for a discussion of this problem for the simple probability of being acquired equation).

This result is verified by the estimates in the last two columns of the table, where I present the results of estimating the more complex nested logit model outlined in equations (29), both by the consistent two-step method[8] and by maximum likelihood on the full model. The estimate of λ is only marginally significantly different from one. It is perhaps not that surprising that there is no strong propensity to be acquired, inducing correlation among the possible acquirers, since acquisition activity culls the strongest candidates from the sample over time. This provides weak and nonrigorous evidence that the assumption of independence across buyers which I made in Section (3) in order to justify a model of buyer choice was not a bad one. Since this "sellers" model and that "buyers" model are not nested, this is not completely convincing evidence.

Nevertheless, encouraged by this evidence that the independence assumption may be somewhat valid, I proceed to set up and estimate an econometric model for the buyers. The valuation equation for the gains which I use will be identical across the models, although the assumptions about the disturbances will not necessarily be consistent with eachother. I let the gain from making no transaction be ν_j, with

----

8. To obtain consistent estimates, I use the method originally suggested by McFadden for the nested logit model, which relies on the factorization of the likelihood given in equation (26). For example, for the sellers' model, I first estimate the parameters of f_{ij} using the likelihood conditional on being acquired, then I form an estimate of I_i, the inclusive value of the possible acquisitions of firm i, and finally I include this variable in the marginal likelihood associated with the probability that firm i is acquired at all (the first part of equation (26) in order to estimate λ and the coefficients in g_i.

an average value of zero.[9] The gain from making a transaction is defined in the same way as in the sellers' model:

$$
\begin{aligned}
(31) \qquad V_{ij}-p_i &= f(X_i,X_j) + d(X_i) - h(X_i) + \nu_{ij} \\
&= v(X_i,X_j) + g(X_j) + g(X_i) + \nu_{ij}
\end{aligned}
$$

where I have partitioned f into the part which varies across acquisitions (v) and the part which does not ($g(X_j)$). The original disturbance $\varepsilon_{ij}-\varepsilon_i$ has been relabelled ν_{ij}, which somewhat obscures the fact that in principle there should be dependence across observations arising from the fact that the acquisition possibilities are the same for all firms. Here things are probably somewhat helped by the fact that I sample from a large set of potential acquisitions to obtain my alternatives. To obtain the estimation equation, I assume the following:

$$
(32) \qquad \Pr(j \text{ buys } i) = \text{Max} \left\{ \underset{k}{\text{Max}} \, (V_{kj}-p_k), \ \nu_j \right\}
$$

If I now place a GEV distribution on the ν_{ij}s and ν_j, allowing for dependence in the ν_{ij}s across acquisition alternatives by including a λ_b parameter, I obtain the nested logit model as before:

----

9. Allowing the no transaction alternative to have a disturbance is necessary if I wish to obtain the conventional nested logit model here. As I show in Appendix 2, the model without ν_j is easily derived and is almost identical in practice, owing to the high probability of this alternative.

(33) Prob (j buys i|D) = Prob(j buys i|D,j buys) • Prob(j buys m, m∈D|D)

$$= \frac{\exp[(v(X_i,X_j)+g(X_i))/\lambda_b]}{I_j} \cdot \frac{I_b^{\lambda_b}}{\exp(-g(X_j))+I_j^{\lambda_b}}$$

where I_j is the inclusive value of the alternatives available to firm j.

In Table 2, I show the results of estimating this model using the same sample of acquisitions as in Table 1, but focusing this time on the alternative choices available to the buyer. This is the form of the model which I estimated in my 1987 paper. As I have shown in this paper, this model cannot be rigorously derived from the statement of the initial problem, unless I assume that any acquisition of a particular type is in potentially infinite supply (so that competitors for the acquisition do not matter).

The results are in fact remarkably similar (within the rather large standard errors) to those in Table 1. In this case, the correlation among the acquisition alternatives is quite significantly different from zero, which implies a stronger propensity to acquire than to be acquired. Also, the test for the no purchase alternative being the same as the others rejects resoundingly ($\chi^2(5) = 3317.3$). The overwhelming message which both sets of results convey is the same as that in Hall (1987): the preference for firms to acquire firms like them, at least in size, R&D intensity, and industry. In addition, a firm's own R&D intensity has no separate effect on its propensity to make an acquisition, while it has a substantial positive effect on the probability of being acquired. In the next section I explore the effects of structuring the choice sets by industry, to see if this can account for some of the results here.

5. Acquisition Probability by Industry

One expects that acquisition alternatives are more alike within industries than between them. That is, a firm which desires to purchase a firm in the electronics industry may evaluate the possible acquisitions in this industry as quite close to eachother, but far from those in, for example, the food industry, even controlling for size and R&D intensity. Or, from the perspective of the selling firm, the probability that the firm will be sold to another firm may be higher once we know it is desired by another firm in the same industry. The nested logit model is capable of modelling this possibility in the same way that I modelled correlation across all acquisition alternatives in the last section. In this section I present such a model and its estimates, and show that for these data, this generalization has very little effect on the estimates of the coefficients of interest, those on size and R&D.

To be precise, I again focus only on those acquisitions which were actually made, and condition on the fact that a purchase occured. This is done primarily to keep the estimation tractable, but we saw in the previous section that this procedure has relatively little effect on the estimates, since the estimated λs were not far from one. In the case of the model of buyers, we may wish to reduce the estimated coefficients slightly because the estimated λ in that case was about 0.6 with a standard error of 0.1.

The model is a two-level nested logit model, where the first level specifies which industry the acqisition is made in, and the second levels specifies which firm in that industry is acquired (or makes the acquisition). The index i denotes the acquisition observation, ℓ denotes the industry, and k denotes the firm within the industry. To keep things manageable, I group the firms into ten industries, which are shown in Tables 3 and 4, and consider a random sample of five firms from each industry; this sample is newly drawn for each observation from the set of firms in that industry which might have made an acquisition (or have been acquired) in that year. This gives me fifty alternatives at the bottom level of the logit model. For this model, the probability that firm i will be acquired by the kth firm in the ℓth industry is given by

$$(34) \qquad \Pr(i\text{-}k\ell \mid i \text{ is sold}) = \frac{e^{V_{i\ell k}/\lambda_\ell} \left[\sum_{m=1}^{5} e^{V_{i\ell m}/\lambda_\ell} \right]^{\lambda_\ell - 1}}{\sum_{b=1}^{10} \left[\sum_{m=1}^{5} e^{V_{ibm}/\lambda_b} \right]^{\lambda_b}}$$

where $V_{i\ell k}$ is the value to firm k in industry ℓ of the ith acquisition and the λs are individual coefficients, one for each industry, which specify how alike the alternatives within that industry are. I write $V_{i\ell k}$ as

$$(35) \qquad \begin{aligned} V_{i\ell k} &= \alpha_1 + \beta_1 X_i + \beta_2 X_{\ell k} + \beta_3 (X_i X_{\ell k}) \\ &\sim \alpha_1 + \gamma X_{i\ell k} \end{aligned}$$

where in the second line I have dropped the X_i term since it is not identified in this model (conditional on acquisition) and combined the last two terms into one which is different for each alternative. The α_ℓs are the average industry specific effect. Equivalently, they might have been included in my original model (section 3) as industry dummies and I will present estimates of such a model in this section.

Some algebraic cranking will show that the following is the appropriate likelihood function for estimating this model:

$$\text{(36)} \qquad \log L(i\text{-}kl|i \text{ sold}) = \alpha_1 + \gamma X_{i\ell k}/\lambda_\ell + (\lambda_\ell - 1) \log I_1 - \log \sum_{b=1}^{10} e^{\alpha_b} I_b^{\lambda_b}$$

where $I_\ell = \sum_{m=1}^{5} e^{\gamma X_{i\ell m}/\lambda_\ell}$ is the inclusive value of the alternatives available in industry ℓ. I note two things about this specification: first, if the αs and λs are all set equal to one, this is equivalent to the multinomial logit model of section 3, but with 50 alternatives rather than 7 included in the denominator of the probability. The estimates of γ are consistent for that simpler model, but slightly more efficient since more information about alternatives has been included. Second, if only the λs are set to one, but αs are included for each industry grouping, the model is equivalent to a multinomial logit model with 10 industry dummies for the industry of acquisition included. In this case, the probability of acquisition by a particular industry is allowed to vary, but there is no correlation among alternatives in a given industry. In addition, because I have fixed the number of alternatives from each industry at 5, the sampling rates for alternatives vary across industry, and this difference in sampling rates will be confounded with the estimates of the intercepts. Since the number of firms in an industry is a known constant at any point in time, it is possible to undo the sampling by weighting the numerator terms appropriately and I have done so in the estimation.

The estimates of this model are shown in Tables 3 and 4 for two versions of the model: the first from the perspective of the seller and the second from the perspective of the buyer. The first two columns present the 7 choice and 50 choice versions of the model with the αs and λs set to one to check that the two sets of alternatives give approximately the same estimates of the coefficients (the values of the likelihood function will not be comparable). The differences in the two sets of estimates appear to be within the standard errors, and as expected, the standard errors for the estimates obtained using fifty choices are slightly smaller than the others.

The fifty alternative model is then estimated with industry dummies (αs) and finally with industry dummies and λs free. The industry dummies are significant in both cases ($\chi^2(9$[10]$)$ = 31.4 and 21.8 respectively). The λs are also significant in the absence of industry dummies ($\chi^2(10)$ = 32.6 and 30.4). Although the gain maximization model would require the estimates of λ to lie between zero and one, many of them come out slightly greater than one, although not really significantly so. When both industry dummies and λs are included, the estimates of both become very imprecise; in addition, the estimates of the coefficients of interest and their standard errors have hardly changed from column 1 of the tables. I conclude that correlation of the unobservable part of the gain from merger within industry groupings is unlikely to bias my estimates of the coefficients of the gain function

----

10. There are only nine industry dummies rather than ten for the usual reason of linear dependence; in all of the models in this paper I have included an overall constant. both on <u>a priori</u> grounds and because the fact that I have sampled from alternatives in forming the denominator would require one in any case. Thus the estimates of the constant are not reported, since they would be meaningless owing to this fact.

very much, if at all.

Because the inclusion of both αs and λs in the model seems unnecessary, and because the estimates of λ are greater than one in general, which is invalid in the context of the nested logit model, I choose to use as my final specification of the model one with industry dummies, but with no groupings by industry in the lower branch. This allows me to take account of the more serious failure of the IIA property which occurred when I included the no-acquisition possibility as one of the alternatives. Although I could combine both models, the estimation would quickly become intractable, since I would need 50 alternatives of each of several hundred possible non-acquisitions and a 3-level nested logit model.

Thus in Table 5, I present the final results of estimating the probability of acquisition from the perspective of both the seller and the buyer. For the sellers' model, I have included a set of dummies for the industry in which the acquisition takes place; note that the λ parameter, which describes the correlation among the gains of the firms which might possibly acquire the firm in question, is now extremely close to unity, implying that not selling looks very much like any other alternative. The parameter estimates themselves have not changed significantly from the last column of Table 1, although they are slightly larger in absolute value. I could also have included a set of industry dummies for the industry of the acquired firm in this version of the model; although significant, these again had no effect on the estimates of the parameters of interest.

For the buyers' model on the other hand, the estimate of λ is even more significantly different from unity, although again the coefficients have not changed much (remember that the effective coefficients are twice as large, of the same order of magnitude as the sellers' model, since they are divided by λ in the estimating model). We already saw that this model could not be justified rigorously by a model of acquisition choice because of the existence of competitors in the merger market. The result here says that a firm which evaluates the gain from an acquisition as large conditional on the acquisition's characteristics tends to evaluate the gain from the other possible acquisitions as large also, inducing a positive correlation in the V_{ij} functions. It seems reasonable that firms might have a "propensity to acquire", but sofar I have been unable to construct a test which would tell us whether the misspecification of the theoretical buyers''model causes serious trouble for these estimates.

6. Conclusions

1) It is nearly impossible to justify a model of buyer's choice, but the estimates from such a model are easier to interpret, and not all that different from those of a sellers' model.

2) The propensity to be acquired is not as strong as the propensity to make an acquisition, possibly because you can only be acquired once.

3) The data accept a model where firms within an industry are not more alike (after controlling for a few characteristics like size, R&D) than like those in other industries, but the ability of the data to have rejected this model is a bit questionable.

4) Other things equal, the gain from a particular acquisition is positively related to the acquirer's size, the acquiree's R&D intensity, and to the distance between the two firms in size-R&D space. It is

negatively related to the acquiree's size (controlling for size and distance), and not related to the R&D of the acquiring firm.

5) The marginal informational content of the more elaborate specifications of the model is small, as usual.

Table 1

Estimates of the Probability of Being Acquired

	Multinomial Logit			Nested Logit	
	7 Choices	5 Choices	Includes No Purch	Two-step Consistent	ML
Number of Obs.	311	311	2359	2359	2359
$\lvert\Delta \log A\rvert$	-.87(.15)	-.88(.18)	-.91(.13)	-.65(.11)	-.77(.13)
$\lvert\Delta(K/A)\rvert$	-3.02(.50)	-3.16(.59)	-2.97(.38)	-2.27(.38)	-2.53(.41)
Same Ind.	2.53(.23)	2.46(.26)	2.09(.14)	1.90(.17)	1.85(.17)
$\log A_j$	1.09(.14)	1.09(.17)	1.07(.13)	.82(.11)	.91(.13)
$(K/A)_j$	.31(.41)	.39(.48)	.22(.35)	.23(.21)	.22(.30)
$\log A_i$			-.65(.12)	-.46(.05)	-.55(.11)
$(K/A)_i$			2.28(.32)	1.69(.19)	1.96(.34)
λ_s	--	--	1.0	.75(.06)	.79(.10)
			-1191.4	-1191.1	-1189.5

Notes:

The estimates shown are for a two-level conditional logit model of the probability of firm i being acquired by firm j. Those in the first two columns are conditional on firm i being acquired, and those in the third column include the alternative of no purchase in the same branch of the logit model. The last two columns present estimates of a two-level model where the first level is sell-don't sell and the second level specifies which firm buys.

A McFadden-Hausman test for IIA in the first two columns passes while that for the third column rejects.

All standard error estimates are consistent in the presence of heteroskedasticity.

Table 2

Estimates of the Probability of Making an Acquisition

	Multinomial Logit			Nested Logit	
	7 Choices	5 Choices	Includes No Purch	Two-step Consistent	ML
Number of Obs.	311	311	2359	2359	2359
$\lvert\Delta \log A\rvert$	-1.00(.17)	-1.04(.19)	-.91(.12)	-.56(.13)	-.62(.13)
$\lvert\Delta(K/A)\rvert$	-3.78(.66)	-4.06(.72)	-2.29(.40)	-2.12(.34)	-1.83(.31)
Same Ind.	2.34(.21)	2.38(.24)	2.04(.13)	1.31(.11)	1.42(.22)
$\log A_j$			1.13(.11)	.45(.03)	.91(.11)
$(K/A)_j$			.002(.35)	.13(.29)	-.08(.32)
$\log A_i$	-.72(.13)	-.75(.17)	-.65(.11)	-.41(.08)	-.44(.10)
$(K/A)_i$	3.30(.48)	3.37(.66)	1.72(.33)	1.73(.29)	1.46(.25)
λ_b	--	--	1.0	.56(.08)	.59(.10)
			-1207.4	-1232.4	-1200.9

Notes:

The estimates shown are for a two-level conditional logit model of the probability of firm j acquiring firm i. Those in the first two columns are conditional on firm j making an acquisition, and those in the third column include the alternative of no purchase in the same branch of the logit model. The last two columns present estimates of a two-level model where the first level is buy-don't buy and the second level specifies which firm is bought.

A McFadden-Hausman test for IIA in the first two columns passes while that for the third column rejects.

All standard error estimates are consistent in the presence of heteroskedasticity.

Table 3

Estimates of the Probability of Being Acquired

by Industry of Acquisition

Coefficient Estimates

	7 Choices	50 Choices	λs free	αs free	Both free
$\lvert\Delta \log A\rvert$	-.85(.13)	-.91(.12)	-1.11(.17)	-.91(.12)	-1.16(.17)
$\lvert\Delta(K/A)\rvert$	-3.49(.51)	-3.24(.45)	-3.81(.59)	-3.37(.48)	-3.95(.61)
$\log A_j$	1.00(.12)	1.04(.10)	1.27(.17)	1.08(.11)	1.37(.17)
$(K/A)_j$	.38(.39)	.20(.32)	-.17(.44)	-.35(.37)	-.48(.47)
Log Likelihood	-430.1	-2781.0	-2764.7	-2765.3	-2756.3
χ^2 vs Col. 2 (df)			32.6 (10)	31.4 (9)	49.4 (19)

Industry of Acquiring Firm	Number of Acquisitions	Estimated α_{ind}	Estimated λ_{ind}	T-stat.*
Non-manufacturing	32	1.48 (.37)	1.93 (.55)	1.7
Food and Chem.	47	0.86 (.20)	0.73 (.21)	1.3
Oil, Rubb,& Plstcs	26	0.46 (.12)	1.68 (.57)	1.2
Metals, SCG	16	0.66 (.20)	0.82 (.44)	0.4
Drugs	14	1.30 (.43)	1.53 (.50)	1.0
Engines & Mach.	51	1.31 (.29)	1.88 (.63)	0.4
Computers & Sci Inst	12	1.33 (.48)	1.45 (.39)	0.2
Elec Mach & Electronics	48	1.48 (.37)	1.26 (.27)	1.0
Transportation Equip.	23	1.09 (.27)	1.38 (.44)	0.9
Misc Mfg N.E.C.	42	1.0	1.40 (.35)	1.1

Notes:

The estimated αs and λs are from the model of Column 5 of the top part of the table.

*The T-statistic shown is for the test that the corresponding λ is equal to unity (zero correlation among firms in the same industry).

Table 4

Estimates of the Probability of Making an Acquisition

by Industry of Acquisition

Coefficient Estimates

	7 Choices	50 Choices	λs free	αs free	Both free
$\|\Delta \log A\|$	-1.04(.14)	-.94(.12)	-1.28(.18)	-.94(.12)	-1.23(.18)
$\|\Delta (K/A)\|$	-4.05(.55)	-3.28(.48)	-4.45(.70)	-3.28(.48)	-4.67(.73)
$\log A_i$	-.72(.13)	-.65(.11)	-.90(.15)	-.65(.11)	-.86(.16)
$(K/A)_i$	3.03(.48)	2.66(.40)	3.40(.59)	2.69(.40)	3.80(.61)
Log Likelihood	-502.3	-2884.7	-2873.0	-2877.4	-2867.0
χ^2 vs Col. 2 (df)			23.4 (9)	14.6 (8)	35.4 (17)

Industry of Acquired Firm	Number Acquired	Estimated α_{ind}	Estimated λ_{ind}	T-stat.*
Food and Chem.	44	0.75 (.56)	1.57 (.94)	0.6
Oil, Rubb,& Plstcs	19	0.49 (.62)	1.46 (.49)	0.9
Metals, SCG	22	1.41 (.78)	0.95 (.32)	0.1
Drugs	16	0.01 (.04)	3.69 (2.01)	0.8
Engines & Mach.	60	0.33 (.25)	1.80 (.50)	1.6
Computers & Sci Inst	28	0.25 (.39)	2.30 (1.04)	1.3
Elec Mach & Electronics	46	0.46 (.29)	1.46 (.40)	1.2
Transportation Equip.	16	0.28 (.39)	1.82 (.95)	0.9
Misc Mfg N.E.C.	60	1.0	0.99 (.24)	0.1

Notes:

The estimated αs and λs are from the model of Column 5 of the top part of the table.

*The T-statistic shown is for the test that the corresponding λ is equal to unity (zero correlation among firms in the same industry).

Table 5

Nested Logit Estimates of Acquisition Probability

with Industry Dummies

	Sellers		Buyers	
	MN Logit	Nested	MN Logit	Nested
Number of Obs.	1565	1565	1565	1565
$\|\Delta \log A\|$	-.95(.12)	-.93(.12)	-.90(.12)	-.51(.07)
$\|\Delta (K/A)\|$	-3.57(.42)	-3.48(.48)	-2.80(.41)	-1.95(.26)
$\log A_j$	1.09(.12)	1.07(.11)	1.08(.11)	.79(.11)
$(K/A)_j$	.20(.41)	.18(.38)	.22(.36)	.09(.35)
$\log A_i$	-.69(.12)	-.73(.15)	-.64(.11)	-.37(.06)
$(K/A)_i$	2.70(.36)	2.83(.47)	2.12(.35)	-1.51(.22)
λ	1.0	1.07(.11)	1.0	0.47(.13)
Log Likelihood	-1135.4	-1135.2	-1169.1	-1164.2
χ^2 for ind. dum.	37.0	37.0	17.6	16.6

Notes:

Columns 1 and 3 are estimates for the model which treats the non-acquisition possibility equally with the other alternatives, as in column 3 of Tables 1 and 2.

The first two columns include a set of ten industry dummies for the acquiring industry, and the second two a set of dummies for the industry in which the acquisition is made.

Appendix 1

The Koopmans-Beckmann Assignment Model with Symmetry Imposed

This appendix shows that the solution to the Koopmans-Beckmann model cannot necessarily be supported by prices when symmetry is imposed, that is, when buyers and sellers are the same set of firms, so that we are considering mergers (of two firms each). This can be done most easily by exhibiting a 3 by 3 counterexample. Let the payoff matrix be the following:

		Buyers 1	2	3
	1	0	5	2
Sellers	2	3	0	4
	3	2	2	0

The nonsymmetric solution to the problem of maximizing the total value of the assignments of buyers to sellers is 1 buys 3, 2 buys 1, and 3 buys 2, with a total value of 11. The prices which support this allocation satisfy the following inequalities:

$$-3 < p_3 - p_1 < 2$$
$$-4 < p_3 - p_2 < -1$$
$$-2 < p_1 - p_2 < 5$$

For example, $(p_1, p_2, p_3) = (2,3,1)$ will satisfy this set of inequalities.

Now consider changing the problem so that the permutation matrix is symmetric; then there are only four possible allocations as solutions: (1-1,2-2,3-3), (1-2,2-1,3-3), (1-1,2-3,3-2), and (1-3,2-2,3-1). By enumeration, the second of these is the optimum, with a total value of

8. From equations (3) and (5) in the paper, the prices which support this allocation must satisfy

$$p_1 > p_2 - 3 \qquad p_2 > p_1 - 5$$
$$p_1 > p_3 + 2 \qquad p_3 > p_1 - 3$$
$$p_2 > p_3 + 4 \qquad p_3 > p_2 - 1$$

or

$$-3 < p_1 - p_2 < 5$$
$$4 < p_2 - p_3 < 1$$
$$2 < p_1 - p_3 < 3$$

But the second condition is obviously impossible to satisfy, so there do not exist prices which support an equilbrium which is also an optimum for this model.

Appendix 2

A Note on Distributional Assumptions in the Nested Logit Model

In section 4 of the paper, I derive a nested logit specification for the probability that a firm is acquired by assuming that there is a independent random component to the price which would be paid for the firm (the disturbance ε_i). This appendix considers the consequences of changing this assumption in two different ways. First I show that the independence assumption is empty, since the observed probabilities would remain unaffected if the natural generalization of the top branch of the logit to allow for dependence were adopted instead. Second, if I had assumed instead that the price of the firm in question was observed and had no measurement error, the equations for the probabilities would change in a non-intuitive way. The purpose of this appendix is to derive these alternative formulations and discuss the reasons for the difference in the expressions, since that sheds some light on the restrictiveness of the logit specification itself.

I begin by simplifying the problem to a case with three alternatives: a firm may either be purchased by one of two other firms (alternatives 2 and 3) or it may remain independent (alternative 1). The mean values of each of these alternatives is denoted μ_i, i=1,2,3. Thus, for example, the probability that alternative 1 is chosen is

(B1) $\Pr(\varepsilon_1-\varepsilon_2>\mu_2-\mu_1,\ \varepsilon_1-\varepsilon_3>\mu_3-\mu_1)$

The GEV distribution of equation (22) may be generalized in the following way to allow for dependence of ε_1 on $(\varepsilon_2, \varepsilon_3)$:

(B2) $$F(\varepsilon_1,\varepsilon_2,\varepsilon_3) = \exp\left\{ - \left[e^{-\varepsilon_1/\gamma} + \left(e^{-\varepsilon_2/\lambda} + e^{-\varepsilon_3/\lambda}\right)^{\lambda/\gamma} \right]^{\gamma} \right\}$$

Note that if γ is set to unity in this expression, equation (22) is obtained. Now I can use the technique of McFadden to compute the probabilities associated with this distribution:

(B3) $$\Pr(2|1,2,3) = \int_{-\infty}^{\infty} F_2(\varepsilon_2-\mu_1+\mu_2,\varepsilon_2,\varepsilon_2-\mu_3+\mu_2)\, d\varepsilon_2$$
$$= \int_{-\infty}^{\infty} e^{-\varepsilon_2} \exp\left\{ - e^{-\varepsilon_2} B^{\gamma} \right\} B^{\gamma-1} A^{\lambda/\gamma-1}$$

where $A = 1 + \exp(\mu_3/\lambda-\mu_2/\lambda)$

and $B = \exp(\mu_1/\gamma-\mu_2/\gamma) + A^{\lambda/\gamma}$

This integral is easily evaluated, to yield the following:

(B4) $$\Pr(2|1,2,3) = A^{\lambda/\gamma-1} B^{-1}$$

Substitution and a slight rearrangement of terms gives:

(B5) $$\Pr(2|1,2,3) = \frac{e^{\mu_2/\lambda} \left(e^{\mu_2/\lambda} + e^{\mu_3/\lambda} \right)^{\lambda/\gamma-1}}{e^{\mu_1/\gamma} + \left(e^{\mu_2/\lambda} + e^{\mu_3/\lambda} \right)^{\lambda/\gamma}}$$

If I set γ to unity and define the inclusive value of alternatives 2 and 3 as

(B6) $$I = e^{\mu_2/\lambda} + e^{\mu_3/\lambda},$$

equation (B5) can be recognized as the product of the marginal and conditional probabilities in equation (23). But now note the following: if I define $\alpha_i = \mu_i/\gamma$, i=1,2,3, and $\sigma = \lambda/\gamma$, the inclusive value I remains unchanged, and the probability of alternative 2 becomes

$$\text{(B7)} \qquad \Pr(2|1,2,3) = \frac{e^{\alpha_2/\sigma}\, I^{\sigma-1}}{e^{\alpha_1} + I^{\sigma}}$$

which is exactly the same form as equations (23); I have eliminated γ from the model, without changing the expression for the probability of alternative 2.

By symmetry, the same argument will eliminate γ from the probability of alternative 3, and hence from that for alternative one by the adding up constraint. Thus the correlation coefficient for the top branch of the nested logit is not identified from the observed probabilities without additional information on the coefficients of the value functions which determine the outcomes. In addition, although the probabilites can be estimated consistently under this model, the underlying coefficients of the mean functions μ_i are estimated only up to a scale factor, unless one is able to assume a particular γ.

The second assumption about p_i which I wish to consider is that it is known without measurement error. In this case, I start from equation (19), but I assume that p_i is known so that there is no disturbance ε_i. I renormalize equation (19) so that I can still follow the derivation of the choice probabilities for the GEV model given in McFadden (1978) with two subtle variations: first, in this case, the required normalization with respect to one of the alternatives is given by the model, since the gain from making no acquisition is zero by definition. Second, the integration of the partial of the distribution function which yields the choice probabilities takes place over a smaller region than in the conventional derivation, since all acquisitions with values below a certain limit are ruled out by the zero cutoff value. With this in mind, I write equation (19) as

(B8) $\quad P_1$ = P(firm i is bought by firm 1) =

$$P(\varepsilon_1 \geq \mu_k - \mu_1 + \varepsilon_k \ \forall\ k \in C,\ \varepsilon_1 \geq -\mu_1)$$

with an obvious simplification in notation. This means that

$$\text{(B9)} \qquad P_1 = \int_{-\mu_1}^{\infty} F_1(\varepsilon_1, \mu_1-\mu_2+\varepsilon_1, \mu_1-\mu_3+\varepsilon_1, \ldots) d\varepsilon_1$$

and similarily for the other alternatives. Some tedious manipulation will show that

$$\text{(B10)} \qquad P_1 = \int_{-\mu_1}^{\infty} \exp(-\varepsilon_1) \exp\left[-e^{-\varepsilon_1}(e^{-\mu_1/\lambda}I)^{\lambda}\right] (e^{-\mu_1/\Lambda}I)^{\lambda-1}$$

$$= (e^{-\mu_1/\lambda}I)^{-1} \exp\left[-e^{-\varepsilon_1}(e^{-\mu_1/\lambda}I)^{\lambda}\right] \Big|_{-\mu_1}^{\infty}$$

$$= \exp(\mu_1/\lambda)\ I^{-1}\ [1-\exp(-I^{\lambda})]$$

where $I = \sum_{k \in C} \exp(\mu_k/\lambda)$

In general, by the symmetry of the problem, the probability that firm i is bought by firm k is given by

$$\text{(B11)} \qquad P_k = \exp(\mu_k/\lambda)\ I^{-1}\ [1-\exp(-I^{\lambda})]$$

By the definition of I, it is also true that $\sum_{k \in C} P_k = 1-\exp(-I^{\lambda})$,

and therefore the probability that firm j will make no acquisition is

$$\text{(B12)} \qquad 1 - \sum_{k \in C} P_k = \exp(-I^{\lambda})$$

which is decreasing in I, the "inclusive value" of the purchase alternatives available. Note that we could have derived this last probability directly from

(B13) $$P(\text{no acq.}) = P(\varepsilon_1 \leq -\mu_1,\ \varepsilon_2 \leq -\mu_2,\ \ldots)$$
$$= F(-\mu_1, -\mu_2, \ldots)$$
$$= \exp\left[-(\sum_{k\in C} e^{\mu_k/\lambda})^{\lambda}\right] = \exp(-I^{\lambda})$$

which is a useful check on the method.

It is easy to see that the conditional probability of acquisition j, conditional on being acquired is the same using this model as using the model in section 4, since in both cases it is equal to $\exp(-\mu_j/\lambda)/I$ (equation (23) in section 4). However, the unconditional probability has a different functional form in the two models, as well as the obviously different normalization which arises when I let the value of the no acquisition possibility have a free mean.

From equation (23), with a slight change in notation to conform to that of this section,

(B14) $$P(\text{no acq.}) = \frac{\exp(-\mu_0)}{\exp(-\mu_0)+I^{\lambda}}$$
$$= 1/(1+I^{\lambda})$$

if I assume that the expected value of no sale is zero (which is not an unreasonable assumption). On the other hand, equation (B13) gives $\exp(-I^{\lambda})$ for this same probability.

But note the following:

(B15) $$\exp(-I^{\lambda}) = (1 + I^{\lambda} + I^{2\lambda}/2! + \ldots)^{-1}$$

so that for I^{λ} sufficiently small, the two distributions will coincide. For the problem on which I am working, the unconditional probability of not being acquired is greater than 0.99. This means that the preceding is of no operational significance, since at this level of probabilty, the value of I^{λ} corresponding to the two models is 0.01005 for the model of this section and 0.01010 for the model of the paper; the difference is too small to have much effect on the estimated slopes and probabilities.

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