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STOCHASTIC-DYNAMIC LIMITING PRICING: AN EMPIRICAL TEST

Robert T. Masson and Joseph Shaanan*

I. Introduction

IN the last decade several papers have enriched the theory of limit pricing. Kamien and Schwartz (1971), Gaskins (1971), Baron (1973), and Flaherty (1980)[1] have made major contributions with dynamic and stochastic models. They predict important new implications for limit pricing and afford an opportunity for more refined tests of this behavior. We test these new implications and provide additional confirmation of limit pricing. Insights into how our tests add to the evidence can be seen by briefly examining the theories and the earlier tests.

Bain's (1956) static model predicts that monopolists in markets with high barriers to entry will "limit price" *to forestall entry,* rather than charge a short-run maximizing price which would encourage entry and lead to lower future profits. It also predicts that monopolists facing low barriers will not limit price, because their opportunity cost of short-run profits forgone to forestall entry is great. When this opportunity cost exceeds the savings from reduced entry, firms prefer the short-run maximizing price. Conversely, when barriers are high, the opportunity cost of forestalling entry is low and firms limit price.

The new models predict intermediate results. By definition, as price exceeds the level at which entry is forestalled, the entry rate or its probability increases above zero. The new theories assume that when price is slightly above the entry-forestalling level, a flood of entry is not induced but a gradual increase in its rate or probability occurs. Firms may thus price to *regulate* the entry rate or probability, not forestall entry. Firms select intermediate prices, setting the marginal entry cost equal to the marginal benefit of a higher price. They reflect Bain's conclusions in the sense that when barriers are low, monopolists may charge high prices, letting entry erode future profits. However, if entry barriers are at intermediate levels, a monopolist's price may be lower. At yet higher barriers optimal prices climb, but often remain above the entry forestalling price.[2]

These models predict that many industries with high concentration would initially have high profits, but that entry would lead to reduced concentration and profits over time. This accords with Bain's (1970) finding that high concentration tends to erode over time and Brozen's (1971) finding that high profits in initially highly concentrated industries tend to erode over time.

Many empirical cross-sectional studies show that measured profit rates are positively correlated with measures of structure—entry barriers and concentration (Weiss, 1974). A related literature has examined entry rates. Harris (1973) and Orr (1974) show entry rates rising as pre-entry profits are higher and falling as barriers are higher.

Both the methodologies and the interpretations of the profit rate studies have been challenged. Brozen (1969, 1971) argues that with "correct" specification, they disintegrate. However, his tests would reject limit pricing if profits eroded over time as the new theories predict.

Demsetz (1973) offers another rebuttal. He notes that firms in an industry may experience efficiencies (i.e., scale economies, superior inputs, or superior foresight). Superior firms will be winners in the market, earning higher profits and expanding their market shares. Industries with such superior firms would then be characterized by high concentration and high profits. Industries without such superior firms should have neither high profit rates nor high concentra-

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[1] A related set of extensions have posited other approaches to entry deterrence (Spence, 1977; Salop, 1979; and Kirman and Masson, 1980).

[2] This is consistent with Gaskins (1970) but not Gaskins (1971), which is a special case in which fringe firms may be driven out.

tion. Empirically he shows that market leaders tend to have higher profit rates. He notes that many studies have used the profit rates of industry leaders as a proxy for industry profits. In his view the demonstrated relationship between concentration and profits reflects superior competitors, not the absence of competition.[3]

We offer a new and more direct method of testing limit pricing based on the new theories. These theories predict a linkage between the profit structure relationship and the relationships between the rate of entry and both barriers and pre-entry profits. With low barriers, the "optimal limit price" (as these newer limit prices are often called) should be above the entry forestalling price. Further, as barriers are increased, the optimal limit price and the entry forestalling price converge. We demonstrate that these theories imply testable relationships. We then estimate both optimal limit price relationships and entry forestalling price relationships using simultaneous equations. Finally we verify that the results are those predicted by the new theories of limit pricing.

II. An Empirical Testing Model

Following the recent terminology, we refer to firms in an industry as "incumbents" and to outsiders as "potential entrants." The pricing/entry process is recursive: Incumbents select a price that determines a level of profit, potential entrants may respond by entering, and the newly defined incumbents select a price again. Potential entrants endeavor to maximize present value, using current profits as an indicator of future profits (i.e., post-entry profits, given any scale of entry, are viewed as a positive monotonic function of pre-entry profits). This generates an entry reaction function, which we assume incumbents recognize. Realizing that higher current profits will lead to entry and lower future profits, incumbents maximize their present value.

We present the empirical model as follows. First, we model entry reactions; second, we model incumbent behavior; and third, we combine both models into a simultaneous equations system. Finally we test and verify the predictions of the stochastic/dynamic limit pricing models.

A. *An Entry Reaction Function*

Potential entrants base entry decisions on the expected present value of entry. We assume that potential entrants project expected future profits from incumbents' profits, industry growth, costs of entry, and their scale of entry. We assume that expected post-entry profits are a positive monotonic function of pre-entry profits for any level of entry.[4] We also assume that an entrant firm can achieve profit rates similar to existing firms' future profit rates net of the costs of entry, treating entry barriers as entry costs. We further assume that there is a level of profits below which potential entrants will not enter. This is the "entry forestalling profit" level, π^f, which is analogous to Bain's entry forestalling price.

We shall assume that expected entry is a linear function of the gap between actual profits, π^a, and the forestalling level of profits if the gap is positive. We shall also assume that the entry forestalling profit rate is a linear function of entry barriers and industry growth.[5] Thus for a typical industry we can model the entry reaction function as the piecewise linear function

$$E(t) = \begin{cases} 0, \ \pi^a(t-1) < \pi^f(t-1) \\ c(\pi^a(t-1) - \pi^f(t-1)), \\ \qquad \pi^a(t-1) \geq \pi^f(t-1) \end{cases} \tag{1}$$

where

$$\pi^f(t-1) = a_0 + a_1 G(t-1) + a_2 S + a_3 K + a_4 A.$$

The variables are defined as

- $E(t)$ is the (expected value of) market share of new entrants during period t,
- $\pi^f(t-1)$ is the industry's entry forestalling profit rate during period $t-1$,
- $\pi^a(t-1)$ is the industry's actual profit rate in period $t-1$,
- $G(t-1)$ is the industry growth rate in period $t-1$,
- S is the industry economies-of-scale entry barrier,
- K is the industry absolute capital-cost entry barrier,
- A is the industry advertising-induced product differentiation entry barrier.

[3] Demsetz' hypothesis is not inconsistent with Bain. For example, Bain defines a superior firm's cost advantage as a barrier, leaving normative implications out of the definition.

[4] We later verify this empirically.

[5] We assume that all variables affecting entry are "predetermined" or exogenous, and clarify this assumption below.

For notational ease we have suppressed any industry index. Except where necessary to avoid ambiguity we shall also drop the time operator in the text.

Equations (1) and (2) can be combined as

$$E(t) = \begin{cases} 0, \; \pi^a < \pi^f \\ -ca_0 - ca_1G(t-1) - ca_2S \\ \quad - ca_3K - ca_4A + c\pi^a(t-1), \\ \quad \pi^a \geq \pi^f. \end{cases} \tag{3}$$

All data on variables in (1), (2), and (3) are available except for the unobservable π^f. We shall demonstrate a method to estimate the portion of (3) for which $\pi^a \geq \pi^f$ to arrive at the parameter values of the c and the a_i's. Given these values we can set $E = 0$ and solve for π^a as a function of the observable variables and estimated parameters assuming $\pi^a \geq \pi^f$ and $E = 0$. This level of π^a is definitionally π^f, so this yields estimates of equation (2), the π^f equation.

We can interpret the composite parameters of equation (3).[6] Clearly entry should respond positively to profits ($c > 0$) and negatively to barriers ($-ca_i < 0, i = 2, 3, 4$).[7] The response of entry to growth ($-ca_1$) has been handled by assumption in the existing literature: entry is generally assumed to be unresponsive to growth ($-ca_1 = 0$) or a positive function of growth ($-ca_1 > 0$).[8] Accordingly we shall hypothesize that it is nonnegative. A positive response to growth would occur if expanding market demand accrued to entrants as under Sylos' Postulate (i.e., incumbents hold output constant with entry). Gaskins' zero-entry response to growth appears myopic. Alternatively, if firms are sophisticated, but incumbents have future production plans from which it is costly to deviate, then entrants may assume that incumbents will continue to grow with the market. This could also yield no entry response to growth.

In terms of π^f, these hypotheses mean that entry forestalling profits are a positive function of barriers ($a_i > 0, i = 2, 3, 4$) and are a nonpositive function of growth ($a_1 \leq 0$). From the π^f equation we can also interpret the constant, a_0. If growth and barriers are zero, entry should occur only if profits exceed the opportunity cost of capital, ρ. Thus we expect $a_0 = \rho > 0$. This implies that for the entry equation $-ca_0 < 0$.

B. *Incumbents' Pricing*

Limit pricing can be achieved only with market power. We assume that the "optimal limit price" will be attained when firms maximize joint profits. We initially examine the "optimal profits" relationship for a cartel, and then analyze industries with less than perfect coordination. We may contrast the "optimal profits," π^0, with the entry-forestalling profit relationship. In figure 1, we illustrate a single entry barrier model to show one possible relationship between optimal profits, π^0, and entry-forestalling profits, π^f. The entry barrier denoted as B can be interpreted as a representative entry barrier or any element of the set $\{S,K,A\}$.

Figure 1 depicts a relationship close to that predicted by Kamien and Schwartz or Baron in their models which are dynamic and also stochastic. They generally assume that the prob-

FIGURE 1.—OPTIMAL PROFITS AND ENTRY-FORESTALLING PROFITS

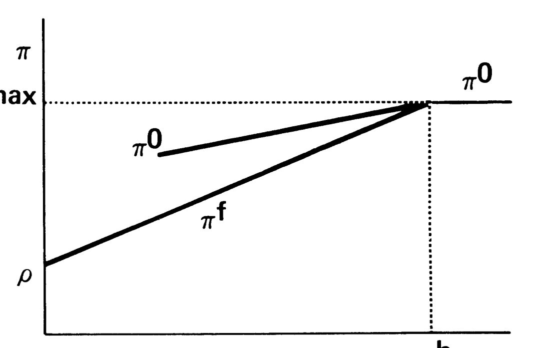

FIGURE 1

[6] Harris (1973) and Orr (1974) have made related estimates. Harris regressed profits on barriers and called the result "limit profits," which he treats as "entry forestalling profits." He then regressed entry on the difference between actual profits and "limit profits." This introduces at least two biases. First, limit profits need not be forestalling profits and second, the omission of concentration leads to excluded variable bias in measuring limit profits.

Orr focused on the determinants of entry. His data on entry measured changes in the number of firms, not in market shares. In one section he included the concept of "limit profits." He includes concentration but he equates "limit profits" with "forestalling profits," leading to biases.

[7] Although the scale of any actual entry rises with S, the expected value of entry falls with S.

[8] Gaskins assumes $a_1 = 0$. Ireland (1972) modifies Gaskins to assume $a_1 < 0$ as do Kamien and Schwartz. Each author handles entrant response by assumption. Flaherty, on the other hand, assumes rational entrants, but asks different questions.

ability of entry rises smoothly from zero as the incumbents' profits rise above their forestalling level. With this assumption they can conclude that $\pi^0 > \pi^f$ unless entry is "blockaded." Blockaded entry occurs when the costs of entry are so high that entry will not occur even if the incumbents maximize profits and ignore the threat of entry. Blockaded entry occurs at B^b and $\pi_{\max}$ in figure 1.

When entry is not blockaded, as profits rise by a small *finite* amount above π^f the expected costs of entry rise by an *infinitesimal* amount because the probability of entry rises smoothly from zero. As profits rise further, the probability of entry rises more rapidly. The optimal profit level, π^0, must then be above π^f unless $\pi^f \geq \pi_{\max}$. Hence, under these assumptions firms never *foreclose* entry whenever barriers are below the blockaded level.

These models may be solved for the expected values of entry rates and profits over time. At any instant, the relationship between optimal profits and barriers will look like the relationship in figure 1. These models predict that optimal profits converge to $\pi_{\max}$ with a positive slope, but they do not require the π^0 line to rise monotonically for its entire range. This is why we do not extend the π^0 line to the vertical axis.

In contrast, Gaskins develops a dynamic/deterministic model. In his 1970 model he shows that above some level of entry barriers $\pi^0 = \pi^f$ for a monopoly without a fringe of sellers or one which is not trying to eliminate competitors. The difference arises because he assumes that the entry rate becomes finite whenever profits are raised finitely above π^f. Given the structure of his model in this case π^0 falls initially from a level at $\pi_{\max}$ if there are no barriers, to π^f at some intermediate level of barriers; and then rises with $\pi^0 = \pi^f$ for higher barriers.

This leaves us with three possible hypotheses about the shape of the π^0 relationship:

H1: $\pi^0 = \pi_{\max}$ for B less than some level and $\pi^0 = \pi^f$ for greater B (in the static/deterministic model as presented by Bain);

H2: $\pi^0 = \pi_{\max}$ for $B = 0$, π^0 declines to π^f and then $\pi^0 = \pi^f$ returning to $\pi^0 = \pi_{\max}$ at $B = B^b$ (in Gaskins' deterministic/dynamic model with no fringe); and

H3: π^0 as in figure 1 always above π^f, possibly falling for low levels of barriers, but rising and converging to $\pi^0 = \pi_{\max}$ at $B = B^b$ (in the models by Kamien and Schwartz or Baron).[9]

We base our estimating equation on hypothesis H3: that π^0 has the shape implied by the stochastic-dynamic models. We later test H3 against H1 and H2. We present the model with the assumption of linearity, testing nonlinearity below:

$$\pi^0(\tau) = b_0 + b_1 G(\tau) + b_2 S + b_3 K + b_4 A. \quad (4)$$

Since π^0 must converge on π^f from above as barriers increase, in the linear case the vertical intercept of π^0 must be greater than that for π^f, but its slope must be less. This may be written:

$$a_0 - b_0 < 0;\ a_2 - b_2 > 0;\ a_3 - b_3 > 0; \text{ and } a_4 - b_4 > 0.$$

The coefficient b_1 is more complex. If π^f falls rapidly with industry growth, then π^0 may fall with higher industry growth. However, if industry growth does not attract entry, then π^0 would rise with growth if there are positive adjustment costs in the model. Previewing our later results, since we empirically find a_1 is weakly negative, we expect (and find) $b_1 > 0$.

The level of optimal profits for a limit pricing monopolist cannot be directly observed if firms within an industry do not jointly maximize as a cartel. However, as for entry-forestalling profits, we may solve for the unobservable, π^0, from observable relationships. To find the unobservable π^0, we assume that actual profit, π^a, will be determined by what π^0 would be if it were attainable, and by the ability of the incumbents to act jointly to attain π^0. We assume that the ability to arrive at π^0 is a positive linear function of concentration, $C(\tau)$. We also assume that π^0 will be reached only when concentration rises to 100%.[10] That is,

$$\pi^a(\tau) = \pi^0(\tau) + b_5\,(C(\tau) - 100), \quad (5)$$

where $b_5 > 0$. Thus we define $b'_0 \equiv b_0 - 100\, b_5$ and combine (4) and (5) to arrive at

[9] If the probability of entry jumps, π^0 might equal π^f at lower B.

[10] $E(t - \tau)$, $\tau = 1, \ldots, T$ might affect $\pi^a(t - 1)$ beyond its effect through $C(t - 1)$. We eliminate excluded variable bias by using a sample where little entry had occurred recently.

$$\pi^a(\tau) = b'_0 + b_1G(\tau) + b_2S + b_3K + b_4A + b_5C(\tau). \quad (6)$$

We shall demonstrate below that this system can be identified and estimated. Once we have estimated this observable relationship we may solve for the unobservable π^0 by setting $C(\tau) = 100$ in (6) and adding this to the constant (i.e., $b_0 \equiv b'_0 + 100\ b_5$).

$$\pi^0(\tau) = b_0 + b_1G(\tau) + b_2S + b_3K + b_4A, \quad b_0 = b'_0 + 100\ b_5. \quad (7)$$

Up to this point, we have developed predictions for the vertical intercepts of π^f and π^0 and for the relative slopes of these functions while varying a single entry barrier. We can also predict the relationship between the relative slopes across entry barriers. Note that $\pi_{\max}$ is defined as π^0 when there is no threat of entry. Hence, $\pi_{\max}$ is independent of which entry barrier leads to blockaded entry. If π^f has a fixed vertical intercept and π^0 a different vertical intercept and $\pi^f(S,K,A) = \pi^0(S,K,A)$ only at $\pi_{\max}$ (which has a single value for any growth rate), then from equations (2) and (7) we may solve for the prediction that $a_2/b_2 = a_3/b_3 = a_4/b_4$. For the linear model the predictions from hypothesis H3 are

(a) $c > 0$;
(b) $a_0 - b_0 < 0$ and $a_0 = \rho$;
(c) $a_1 \leq 0$ and $b_1 > 0$ if a_1 is weakly negative;
(d) $a_i - b_i > 0$, $i = 2,3,4$;
(e) $b_5 > 0$; and
(f) $a_2/b_2 = a_3/b_3 = a_4/b_4$.

C. *Simultaneity and Identification*

There are two sources of possible simultaneity: (1) the simultaneity of advertising and profits within the π^a relationship, and (2) the simultaneity of profits between the entry and profits equations.

Martin (1979) has found advertising to be simultaneously determined with profits. We have some reservations about the significance of his result.[11] However, if the model is identified with respect to the simultaneity of entry and profits, as we demonstrate below, we can test for additional simultaneity between advertising and profits in our sample by performing the Wu test (see Farebrother (1976)). This test involves assuming that advertising is endogenous and estimating a set of equations using a methodology similar to Martin, but including both predicted and actual values of advertising in the second stage. Applying the Wu test to our sample, we verified that endogeneity of A is not significant.[12] Accordingly we present our model under the conventional assumption that advertising is predetermined in the model.

We handle the problem of simultaneity between entry and profit by recognizing that our model is recursive. It describes optimal short-run equilibria, in which price can be set in the short run but entry can respond only after a lag. This permits the model to be identified by recursion.

The model may be described by two estimating equations with two endogenous variables, $\pi^a(t-1)$ and $E(t)$. Concentration in time period $t-1$ is a function of entry in period $t-2$ and earlier periods. Thus, the effect of entry in time t has no feedback effects on concentration, and hence profits, in period $t-1$.[13] We thus treat concentration in period $t-1$ as a predetermined (exogenous) variable when determining $\pi^a(t-1)$.

To exhibit recursive identification, we rewrite equation (3) for $\pi^a \geq \pi^f$, and equation (6) in block recursive form:

$$\pi^a(t-1) = b'_0 + b_1G(t-1) + b_2S + b_3K + b_4A + b_5C(t-1) + \epsilon(t-1) \quad (6')$$

$$E(t) - c\pi^a(t-1) = -ca_0 - ca_1G(t-1) - ca_2S - ca_3K - ca_4A + \eta(t). \quad (3')$$

A sufficient condition for identification is $\text{cov}[\epsilon(t-1), \eta(t)] = 0$. As long as entry reacts to reported profits, this condition will be satisfied.[14] Once recursive identification is demonstrated,

[11] One must suspect some endogeneity, but it is unclear how important it would be in practice. If some products are inherently non-advertised and others inherently require advertising, then simultaneity as a practical matter may be nil. We are hesitant simply to accept Martin's results because his sample includes almost all SIC industries and he compensates for mismeasurement solely by including an index of geographic dispersion. There are problems with this approach (Scherer, 1980) so we test for simultaneity with our sample.

[12] The test results are available upon request.

[13] Recalling the sample has little recent past entry (see n. 10).

[14] Short-term mismeasurement of $\pi^a(t-1)$ could lead to a spurious correlation. We reduce the effects of such short-term errors by estimating $\pi^a(t-1)$ as the average profit rate of several years preceding entry. Ex post analysis of the error structure supports the independence assumption.

then $\pi^a(t - 1)$ may be treated as predetermined (exogenous) for estimation of equation (3′).

III. Estimation

We obtain our data from Harris (1973) and Shepherd (1970). Similar results have been derived using other data.[15] The 1950–66 period analyzed can be broken roughly into a pre-entry period, $t - 1$, in 1950–1957, and an entry-initiation period, t, in 1958–63. The remaining sample years are needed in some cases to indicate how large a market share entrants achieved.

We have collected measures of each of the above theoretically specified variables.

1. $E(t)$ comes from Harris' measure of the market share of domestic entrants into 37 manufacturing industries. Harris found entry by tracing the top 1000 firms from Fortune's *Plant and Product Directory* for 1966, other firms from *Standard and Poors Industry Studies*, and yet others from case studies back to 1950 using Moody's, Standard and Poors, *Thomas' Register of Manufacturers* for 1950, firm annual reports, and SEC 10-K forms. We use Harris' measure of *de novo* entry.
2. $\pi^a(t - 1)$ comes from Harris' estimates of dominant firms' profit rates on equity for the years preceding major entry.
3. $C(t - 1)$ is Shepherd's four-firm concentration ratio for 1947.
4. S, from Harris, is defined by "average large plant size" as a percentage of sales. "Average large plant size" is the average size of the least number of plants accounting for two-thirds of industry output. (All plants with 500 or more employees were also included.) This is similar to the Comanor and Wilson definition (1967). Bain's (1956) engineering study overlapped for 17 observations and was correlated at 0.94 with our S.
5. K, from Harris, is S times industry book value in 1958.
6. A, from Harris, is industry advertising as a percentage of sales in 1954–57.
7. $G(t - 1)$, from Harris, is the *pre-entry* growth rate of sales.

We note two non-linearities which affect estimation. The profit equation (6) has potentially significant non-linearities because by hypotheses H1 and H2 π^0 will initially fall as barriers rise. We tested the linear specification using both non-linear specifications and analyses of the residuals. We accepted the linear form after testing. The non-linearities in the entry equation (3) are of a different nature. Recall that equation (3) changes as $\pi^a \gtreqless \pi^f$ and that entry is defined as non-negative. These two features required a limited dependent variable approach to estimation based upon a modified Tobit analysis. The procedure uses a recursive technique to limit the sample to observations where $\pi^a \geq \pi^f$ and is described in the appendix. The biggest statistical cost associated with this technique is that the measurements of the constant terms in the E and π^f equations are highly sensitive to potential measurement error of π^a in one or a few observations. We report a range of estimates for the constant in the E and π^f equations and do not report t-values. (Within the reported ranges, the t-values for the constant were not significantly different from zero at the 95% level in either equation.)

The estimates of the E and π^a equations are presented in table 1. All coefficients have their predicted signs.

Profits attract entry and barriers reduce it as predicted, although the K effect is insignificant. The effect of growth on entry is non-negative, and its insignificance is consistent with the hypothesis. Concentration, growth, and barriers raise profits as expected, although the K effect is insignificant and S is only significant at the 90% level.

Next we solve for π^f and π^0, the central focus of our hypothesis testing. Equation (3) is converted to the π^f equation (2) by setting $E = 0$ for $\pi^a \geq \pi^f$ and solving for profits. Significance levels for the π^f equation are from Wald tests. Equation (6) is converted to the π^0 equation (7), setting $C = 100$ to arrive at b_0. The results are presented in table 2. Equation (8) is defined by $\pi^f - \pi^0$ to test hypotheses about the signs of $(a_i - b_i)$ terms.

We can now examine the predictions implied by H3—stochastic/dynamic limit pricing:

(a) Entry is a positive function of pre-entry

[15] We used price-cost margins and also tried Mann's (1966) measures of concentration and barriers for a smaller sample. The qualitative results are similar. (See, for example, Shaanan (1979).)

TABLE 1.—THE ESTIMATING EQUATIONS
(coefficients and t-statistics)

Equation	Dependent Variable	Coefficients	Constant	$C(t-1)$	$G(t-1)$	S	K	A	$\pi^a(t-1)$
(3)	if $\pi^a \geq \pi_f$, $E(t)$	$(-ca_i)$'s and c	[−2.18, −0.36]	n.a.	0.200 (0.62)	−0.379[b] (2.77)	−0.034 (1.07)	−0.250[b] (1.99)	0.498[b] (1.88)
(6)	$\pi^a(t-1)$	b'_0 and b_i's	4.28[b] (2.80)	0.047[b] (2.38)	0.783[b] (5.27)	0.139[a] (1.36)	0.008 (1.24)	0.159[b] (1.80)	n.a.

Note: n.a. means "not applicable."
[a] Significant at the 10% level.
[b] Significant at the 5% level.

profits: $c > 0$. This is verified in table 1 at the 95% level.

(b) The intercept of π^0 should exceed the intercept for π^f, and the intercept of π^f should be the opportunity cost of capital: $a_0 - b_0 < 0$ and $a_0 = \rho$.

We report a range of values for estimates of a_0. We also have an estimated standard error for our estimated maximal a_0 (see appendix). Accordingly, we can conservatively test whether our highest estimate of a_0 leads to $a_0 - b_0 < 0$. This difference is significant at the 90% level.

We can test whether $a_0 = \rho$. McDonald (1971) estimated the necessary rate of return to attract equity capital in the late 1950s at about 5% and the Aaa bond rate was about 4%. The estimates of a_0 overlap with this range. The lowest estimates of a_0 are outside this range, but equality cannot be rejected.

(c) Growth should not raise π^f (lower entry); if it lowers π^f only weakly, then π^0 should rise with growth: $a_1 \leq 0$ and $b_1 > 0$ if a_1 is weakly negative. We find that $a_1 < 0$ and is insignificant, which is consistent with the hypothesis. We find that $b_1 > 0$ is significant at the 99% level, which verifies our expectations.

(d) The π^0 and π^f curves should converge: $a_i - b_i > 0$ for $i = 2,3,4$. We find that $a_i - b_i > 0$, $i = 2,3,4$. For $a_2 - b_2$ (scale economies), this is significant at the 90% level. The evidence suggests convergence.

(e) Concentration facilitates achieving higher profits: $b_5 > 0$. This is significant at the 95% level.

(f) $\pi_{\max}$ should be unique, implying that the ratios of the slopes of the π^f to π^0 lines should be equal regardless of the entry barrier varied: $a_2/b_2 = a_3/b_3 = a_4/b_4$. The estimated ratios are $a_2/b_2 = 5.5$; $a_3/b_3 = 9.0$; $a_4/b_4 = 3.15$. Pairwise tests of the form $a_i/b_i - a_j/b_j = 0$ yield t-values of 0.28, 0.42, and 0.50 for (i,j) equal to (2,3), (2,4), and (3,4), respectively. The equality of the ratios cannot be rejected.

These tests support hypothesis H3, which is implied by the stochastic/dynamic limit pricing models of Baron or Kamien and Schwartz. They also enable us to reject hypotheses H1 and H2, the static Bain hypothesis and the dynamic/deterministic Gaskins hypothesis.

Hypotheses H1 and H2 *require* π^0 to be convex, initially high with low barriers, falling to π^f, and rising along π^f. Hypothesis H3 *allows* π^0 to be convex, with its rising section *above* π^f. If H1 or H2 were correct we should find either that π^0 is convex, or that $\pi^0 = \pi^f$ if the sample has no small barrier observations. We can reject $\pi^0 =$

TABLE 2.—THE COEFFICIENTS OF π^f, π^0 AND $(\pi^f - \pi^0)$

Equation	Dependent Variable	Coefficients	Constant	G	S	K	A
(2)	π^f	a_i's	[0.71, 4.37]	−0.401 (0.50)	0.761[b] (1.97)	0.068 (1.02)	0.501[b] (1.70)
(7)	π^0	b_i's	8.98[b] (8.09)	0.783[b] (5.27)	0.139[a] (1.35)	0.008 (1.24)	0.159[b] (1.80)
(8)	$\pi^f - \pi^0$	$(a_i - b_i)$'s	[4.61, 8.41][c]	−1.184[a] (1.46)	0.622[a] (1.57)	0.060 (0.90)	0.342 (1.11)

[a] Significant at the 10% level.
[b] Significant at the 5% level.
[c] Using an estimated standard error of 3.01, the value 4.61 is significant at the 90% level.

π^f. We also tested π^0 for non-linearities using analysis of residuals and non-linear specifications, and found no evidence of convexity. Accordingly, we accept H3, stochastic/dynamic limit pricing, and reject H1 and H2, deterministic limit pricing.

These are new and powerful results. Consider the alternatives. If there were no meaningful barriers, then π^f should not rise above ρ as S, K or A rise. If there were no limit pricing then π^0 should be horizontal unless profit-structure correlations can be explained by Demsetz' superior firm hypothesis. But if high π^a reflects only superior efficiency of market leaders, then entry should not be rising with π^a. Finally, the convergence of profit rates shown by Brozen is predicted by such limit pricing.

The model can also be used to estimate $\pi_{\max}$ and the blockaded level of entry barriers. Using the median estimate of the constant term and assuming all barriers are at mean values, $\pi_{\max} = 10.58 + 1.08G$. For each barrier we can show its blockaded level assuming each other barrier is zero. Since the blockaded level is a rising function of G, we evaluate blockaded barriers at mean G and twice mean G (the upper decile). Using the median constant term with mean G and twice mean G we arrive at blockaded levels of $S^b = [18\%, 27\%]$, $K^b = [\$191 \text{ million}, \$275 \text{ million}]$ and $A^b = [34\%, 48\%]$. The sample means of S, K, and A were respectively 5%, \$29 million, and 4%, whereas the sample maxima were 15%, \$375 million, and 19%.[16]

Only two industries were estimated as blockaded: autos and (marginally) steel. For the period analyzed these estimates are reasonable: autos were still experiencing net exit and steel was relatively stagnant.

The parameter estimates, although reasonable, should be interpreted with caution. Blockaded levels and $\pi_{\max}$ are both highly sensitive to estimates of slope coefficients. Furthermore, if a single firm could achieve higher profits than an industry with a four-firm concentration of 100%, then estimates of blockaded levels and of $\pi_{\max}$ are biased downwards.

IV. Conclusions

The tests we performed verify that our measures of entry barriers reflect factors which inhibit entry. They also verify that entry responds to pre-entry profit rates. Finally, we show that the level of entry forestalling profits is rising with the level of entry barriers, as the theory of entry barriers predicts.

We tested a profit equation like the traditional profits-structure tests in the literature: profits rising with both concentration and entry barriers. We note that theory does not imply monotonicity in barriers, but testing shows that it cannot be rejected in this sample. More importantly, we then use the profits relationship to derive an estimate of the unobservable optimal profit level which would be selected by a highly concentrated industry given any set of entry barriers.

We used these two relationships to test limit pricing. We demonstrate that the implications of traditional limit pricing to forestall entry may be rejected, but verify the predictions of the recent stochastic-dynamic limit pricing theories.

The tests permit parameter estimates of heretofore unobserved variables such as entry forestalling profit levels, optimal profit levels, and blockaded levels of entry barriers. They also support the stochastic-dynamic limit pricing model predictions. Their strength is that they suggest that concentrated industries do limit price, but in a fashion consistent with the empirical observation that highly concentrated industries tend to lose market shares and profits over time.

APPENDIX

Estimation of the E and π^f Equations

The entry equation (3) is piecewise linear with a limited dependent variable. This presents two problems: limiting the sample for $\pi^a \geq \pi^f$, and estimation. With a limited sample, heteroscedasticity-adjusted Tobit seems appropriate. Unlike simple regression, heteroscedasticity biases Tobit estimation.

The standard Tobit model assumes an underlying true relationship with a constant error variance and then "censoring" of the dependent variable. Censoring in our context is equivalent to making exit part of the same linear relationship as entry, but unobserved. I.e., a standard Tobit would be $E = \beta X + \eta$ if $\eta > -\beta X$ and $E = 0$ if $\eta \leq -\beta X$ where $\eta \sim n(0,\sigma^2)$. In this model positive values of E could arise as mismeasurement despite net exit.

[16] The industries at the maxima are respectively cereals, autos, and soap. The FTC contended that S for cereals was only about 4%. The defense, however, has estimated that it was higher than 15%. The results of out tests are insensitive to assuming an S of 4% or dropping cereals. For consistency we used the 15% figure. The second highest values of the barriers to entry measures were 14%, \$142 million, and 15% for typewriters, steel, and perfumes.

Given the data characteristics, we know that any measured $E > 0$ must occur because true entry is positive; however, the entry level may be subject to mismeasurement. Values of $E = 0$ could be a mismeasurement of true $E > 0$. We shall assume that small values of true entry are subject to small measurement error but large values of true entry are subject to large measurement error. If notationally we define (3) as $\pi^f = \beta_0 + \beta_1 X$, then for estimation (3) is hypothesized to be:

$$E = \begin{cases} 0, \ \pi^a < \pi^f & , \\ c(\pi^a - \beta_0 - \beta_1 X) + \epsilon, & \epsilon > -c(\pi^a - \beta_0 - \beta_1 X) \\ 0 & , \ \epsilon \leq -c(\pi^a - \beta_0 - \beta_1 X) \end{cases}, \quad \pi^a \geq \pi^f$$

where $\epsilon \sim n(0,\sigma^2(\pi^a - \pi^f))$.

We used the following iterative estimation procedure. First we estimated the full sample using Tobit analysis. We note definitionally that if $E_i > 0$ for observation i, then $\pi_i^a > \pi_i^f$. Second we found an estimate for π^f denoted $\Pi^f = B_0 + B_1 X$ where B_1 is estimated β_1 from the Tobit analysis and $B_0 \equiv \max_i\{\pi_i^a - B_1 X : E_i > 0\}$. Both are defined by the frontier of all observations, i, for which $E_i > 0$ (e.g., for which it is revealed $\pi^a > \pi^f$). Third we excluded all observations for which $\pi_i^a < \Pi_i^f$ and ran a heteroscedasticity-adjusted Tobit using $\pi_i^a - \Pi_i^f$ as the deflator. Fourth we recalculated Π^f, B_0, and B_1 as before and repeated the adjusted Tobit process. We iterated until the excluded sample points and the parameters converged, and verified that heteroscedasticity was adjusted for in the sample.

Convergence occurred with $\pi^f > \pi^a$ for autos and steel; the expected value of entry was positive for 35 to 37 industries. In the E and π^f equation in tables 1 and 2, the constant terms furthest from zero in absolute value are the Tobit estimators, and the constants closer to zero are adjusted frontier estimators based upon B_0. The constant term in the $\pi^0 - \pi^f$ equation was tested using the Tobit constant and standard error. Measurement error of profits in the industry establishing the frontier estimate of π^f could reduce the significance of the constant in $\pi^0 - \pi^f$ because only underestimates of profits would lead to errors in the frontier estimate (e.g., without measurement error significance would be at least as great or greater). The industry establishing the frontier was watches and clocks, with $\pi^a = 6.82\%$ and $E = 0.26\%$.

The two estimators of the constant are subject to various interpretations. The Tobit estimator (the higher constant) may be correct if $\text{var}[\epsilon] = \sigma^2(\pi^a - \pi^f - k)$, where k is our adjustment factor if

(a) the soap and the watches and clock industries (both with $E_i = 0.26\%$) had actual $E_i = 0$ but were mismeasured,

(b) the model structure is based on net entry, with exit censored, and exit exceeded 0.26% in both industries, or

(c) π^as in these two industries are mismeasured, possibly due to overaggregation (e.g., highly profitable subindustries existed as might be suggested by the product line approach used by Biggadike (1979)).

The alternative adjusted constant could be a better (linear) estimator if instead $\text{var}[\epsilon] = \sigma^2(\pi^a - \pi^f)$, π^a is measured without error, and E is actually convex in $\pi^a - \pi^f$ for small values of this difference.

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