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The Effects of Vertical Integration on Oil Company Performance

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ABSTRACT

When asked to rank industries by their degree of vertical integration, most people would agree that the oil industry should come top of the list. Underlying this belief is the fact that integration and size tend to be closely associated. As the oil industry is so large and oil companies so visible and perceived as so profitable, the common belief is a correlation between vertical integration, size and performance. If a dynamic view is taken of this cross-sectional observation we would expect to find an oil industry populated only by fully integrated very large companies. However, a closer look at the industry shows a large dispersion in the segments in which companies participate, and even companies in the same segments use the market in different degrees. Furthermore, the average degree of integration of the industry does not exhibit a specific trend over time. The only periods when trends are seen are periods of either large uncertainty (the intra-war periods) or large market power (the period of existence of the Standard Oil Trust).

Although the public and the government agencies may have a view of the large advantages of integration, the surprising fact is that many empirical studies do not focus on its costs. The observation of dispersion and stability of integration would suggest, as theoretical studies do, that a cost-benefit analysis of integration is needed. This study uses that driving hypothesis and tests for the costs and benefits of integration.

The measure of costs of integration should reflect the effects of slack, diseconomies of size and diseconomies of diversification. The obvious choice is a measure of efficiency, namely technical efficiency, that looks at waste assuming inputs are used in the right proportion. The advantages of integration are traditionally set in terms of reliable supply of inputs or reliable demand for outputs. As the existence of uncertainty is a feature of oil markets, a test of uncertainty is made in the form of variability of efficiency. The use of efficiency in both tests is made for the purpose of consistency and is incorporated in the same econometric framework.

The cost-benefit analysis would suggest that each company pursues integration up to the point where its benefits are outweighed by its costs. The results in this paper confirm just that: vertical integration reduces the *level* of efficiency of companies while it also reduces its *variability*. In other words, there are diseconomies of diversification but the market also incorporates inefficient volatility. However, the results are not impervious to change, there are periods when the inefficiency associated with integration is smaller as is also the risk-reducing ability of the strategy. This may help to explain the reasons why different degrees of integration may be optimal.

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INTRODUCTION

The oil industry has always been fertile ground for an analysis of the reasons for and effects of vertical integration. One of the reasons for this popularity is that stages of production are easily differentiated. Furthermore the association between market power and integration, usually made by the public, is believed to be evident in the case of the oil industry. The perception is that integration is a requirement for company success as the oil industry is populated by large integrated companies that make "excessive" profits. The identification of market power with vertical integration was taken as an axiom by regulatory agencies in the 1970s and has only recently been abandoned (Yarrow (1991)). For example, the US oil industry was the subject of a complaint by the Federal Trade Commission in 1973, and of a prior report that recommended divestiture as a means to control the anticompetitive strategies of the participants (Teece (1976)).

It is difficult to reconcile the idea of significant advantages to vertical integration with the empirical observation of a large number of producers participating in different stages of the oil industry. Furthermore companies of similar sizes involved in the same segments of the industry differ in their degree of reliance on the market. The coexistence of companies with varying degrees of integration in a narrowly defined industry suggests that a cost-benefit analysis of the integration strategy must be the testing hypothesis.

The superiority of internal rather than market transactions predicted by the transactions cost approach is one of the extensively tested advantages of integration. In contrast recent studies have focused on diseconomies of size and diversification as the costs of integration. These two hypotheses are tested in this paper within a single framework. First, the hypothesis of diseconomies of vertical integration, controlling for market power, is tested by analysing the determinants of efficiency of US oil companies. Finally, the transactions cost approach including uncertainty effects are tested by means of a test of variation in efficiency. These two tests are carried out within the same econometric estimation.

The study is divided in nine parts. Chapter 1 briefly surveys the theory of vertical integration and the effects it has on firm performance in terms of costs and benefits, while Chapter 2 reviews the inter- and intra-industry empirical evidence. Chapter 3 describes the measures of integration traditionally used and introduces those applied in this study. This is followed by a description of the data sample used and the patterns of integration found in our empirical material. The empirical model which tests our hypothesis is developed in Chapter 5; with the definition of variables and the estimation procedure in the two next chapters. Chapter 8 presents the estimates of efficiency and assesses their robustness to model, sample and period changes. Chapter 9 concludes.

1. EFFECTS OF INTEGRATION

The reasons for vertical integration have been studied from at least three different perspectives: the neoclassical theory of the firm, the theory of contracts, and the theory of markets. All three approaches have identified reasons and possible results deriving from the decision to integrate. However, a casual look at the integration strategies of different industries, even different companies in a narrowly defined industry, shows a large dispersion in the degree of integration. This observation suggests that the way to approach the issue of integration is by means of analysing its costs and benefits.

Advantages of Integration

This section looks at the economies derived from vertical integration at the firm level.

Vertical integration may arise out of technological economies. In other words, less inputs may be required to produce a given output in the downstream process if the firm is also engaged in the upstream process. Technological economies arise because of the nature of the product and are regarded as a *sine qua non* requirement to integrate. Consequently, if the efficiency gains derived from integration are too large the scope for strategic behaviour using integration as the decision variable is very narrow. Technological economies mean that the efficiency frontier of the downstream process is larger with integration into input production.

Within an industry, the reasons for integration are closely linked to the exercise of market power, or to any other market-related imperfection. Imperfect competition at a given stage of production gives rise to several incentives to integrate vertically. The textbook example is the case of an upstream monopolist faced with a competitive industry downstream. In the case of variable-input technology the competitive segment is substituting away from the monopolist's output. In other words, the competitive industry uses too little of the monopolist's output. By integrating forward, the monopolist can convert that efficiency loss into its own profit and therefore expand input use to the optimal level. However, this case only arises if the input is used in variable proportions. In the case of fixed proportions final demand for the downstream output is identical to the demand for the monopolist output. In that case, the monopolist has already internalized the efficiency gain, and no gains can be realized by forward integration.[1] In the case of U-shaped average cost curves the absence of integration and the use of monopoly pricing can lead to a suboptimal number of

[1] Notice how the analysis does not say anything about the overall welfare effects of integration. In order to do that we would have to look at the resulting price after integration. However, this effect is outside the scope of this paper as we are interested in firm-specific results only. For a review of this extensively analysed issue see Perry (1989).

firms (Quirmbach (1986)).

A second related reason for forward integration by producers is the separation of downstream markets for the purpose of price discrimination. Consider the case of a monopoly selling to two industries, one facing an inelastic and the other an elastic product demand. Although the manufacturer could integrate forward in both markets and thus internalize the efficiency gain by contracting input use in the former and expanding it in the latter, the same result could be achieved by integrating only into the market with the elastic demand. The desired price rise in the inelastic market is achieved by contracting sales to the market while increasing input use in the elastic segment. This would again lead to internalized efficiency gains.[2] The efficiency incentive for backward integration by a monopsonist supplied by a competitive industry upstream can also be made. Without integration the high supply price leads to too little input employment. By the same reasoning above, vertical integration allows the monopsonist to appropriate the efficiency gain.

The possibility that vertical integration may lead to barriers to entry and therefore excess profits has been known since the work of Bain (1956). By integrating into an additional stage of production, the producer has raised the capital requirements to entrants. The reason is that profitable entry can only occur by investing in entry in more than one stage. Similarly, a firm may raise its rivals' costs by vertical integration; leaving the market thin and thus restricting the expansion of competitors (Waterson (1993)).

These arguments for vertical integration and the resulting increases in efficiency may seem odd to people in business. In fact, the argument most widely made by industry concerning the advantages of integration is security of supply, for backward integration, and security of markets, for forward integration. This argument cannot be related to random shocks that affect the security of supply or markets for all companies identically. For the avoidance of the randomness, were it possible, is not an advantage as it would lead to the loss of important information and therefore to efficiency losses. The security argument rather, may refer to the situations in which the firm finds itself unable either to sell its output or buy its input. That is situations in which as a result of imperfections the market is not clearing and reliance on its use carries a cost.

The losses arising from using the market are related to the imperfect information and transaction costs. The pioneering article on information is Arrow's (1975). His model incorporates randomness in the output of the upstream industry although its constituent firms have information

[2] The extension to *N* markets is made by Perry (1978a) and the empirical application to the case of the aluminium manufacturer Alcoa is made by Perry (1980).

on output one period in advance. This information, which is highly valuable because capital decisions must be made in the period preceding production, can be internalized by the downstream companies by backward integration. Thus, backward integration enables the manufacturer to make a better prediction of the input price and, therefore, a more profitable investment decision. In a similar vein, agency problems can be overcome by outright vertical integration as in the models of Crocker (1983) and Riordan and Sappington (1987). As in Arrow's model the incentive to integrate in these two models arises because important information may (but this is not guaranteed) be revealed by integration. Furthermore, agency problems may still persist because delegation within the company will be necessary after it enters a new stage.

The previous paragraphs have discussed motivations for integration arising from market imperfections. However, perhaps the most popular explanation of vertical integration is that derived from the cost of transactions. The reasons for this popularity are its intuitive appeal and the clear testable propositions arising from the theory. The following lines cannot give full justice to such a rich analysis but we will try to summarize the main thrust of the approach.[3]

Transaction costs do not arise from some market imperfection, but mainly from what Williamson calls asset-specificity. The idea is that when deciding to engage in a market transaction the industry may be competitive *ex ante*, but once the decision has been taken specific investments are made which have effectively locked both parties into a bilateral monopoly situation. As a result the intermediate input market for the two firms cannot be said to exist (Perry (1989)). The lack of alternatives arises, for example, when there are economies of scale relative to industry demand in both upstream and downstream markets. Williamson (1975) has identified how asset specificity may arise from five different types of investments: (1) investment in specific physical capital, (2) in specific human capital, (3) in site-specific capital, (4) in dedicated capital, and (5) investment in brand name capital.[4] When the environment is uncertain the transaction costs of writing and enforcing contracts make it prohibitively costly to devise long-term contracts which specify all obligations under all contingencies. The bilateral relations fail to define the terms of performance under all states of nature and the scope for opportunistic behaviour in uncertain situations increases.

Thus far, the models reviewed here highlight the benefits derived from integration in the form of

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[3] See Williamson (1975) and (1985).

[4] Transaction-specific assets give rise to what Klein, Crawford and Alchian (1978) call appropriable quasi rents (i.e. the difference between the value of the asset in this use and its next best use).

increased profits. However, if only these considerations were important we would expect the firm to increase its size without bound. The following section introduces the concepts of diseconomies of integration.

Costs of Integration

If firms are equally sized in a specific-stage of the industry, then the addition of one stage of production will result in a correlation between size and integration. Similarly in a more dynamic model, if the advantages of integration outweigh its costs, we would expect highly integrated firms to grow large. Against the idea of a positive correlation between size and integration is Stigler's (1951) argument that young industries tend to be characterized by high degrees of integration as the division of labour is limited. Industries will initially be oligopolistic in their early stages of development and as they expand may become more competitive as the division of labour correlates with the size of the market.[5]

However, at some point in time the decision to integrate will lead to the production by the firm of inputs hitherto purchased from outside. There may then be costs associated with the organization of production within a firm. Other things given, the greater the number of factors of production, the greater are the costs associated with either growing or entering a new segment of the industry.[6] Although Williamson (1974) points to factors limiting the efficiency of markets, he also recognizes the limits to size imposed by the diseconomies of firm scale. A very important component of the costs of growing large is linked to managerial diseconomies. This arises, because managerial ability is a scarce resource and because the greater the number of assets under the manager's control the greater the rate at which he must make decisions or the more decision-making he must delegate (Canes (1976)).

Related to the problem of managerial diseconomies is that of control. As the firm integrates the complexity and the degree of differentiation of its structure increases. As a result the need to monitor different stages of production also increases with the ensuing demands on the top hierarchical management tier. Thus, control is not only a matter of size, but may have a prominent role to play in coordinating new stages because of the non-specialization of production. The

[5] This would presumably affect all companies in the industry equally. For an empirical analysis of Stigler's hypothesis see Levy (1984).

[6] The existence of costs of adjustment form part of the studies that reject Gibrat's law (e.g. Evans (1987), Barrera (1994)). Gibrat's law claims that growth is independent of size, whereas most empirical studies find that smaller firms may fail more often but also grow faster.

acquisition of new knowledge may prove to be expensive and the more so the more stage-specific knowledge is. Thus, the costs of coordinating stages are inversely related to the similarity of processes and the possibility to share innovations (Armour and Teece (1980)).

Whether diseconomies of production are related to size or stages of production, the problems of agency still arise. In other words, while the uncertainty models reviewed above highlighted how information can be acquired by means of vertical merger, integration in fact generates employee-specific information and growing delegation. Agency theory points out that transaction costs do not simply disappear when hierarchy is chosen over the market. As a result agent's rather than supplier's (or buyer's) opportunism may arise.

To conclude, it seems that firms will decide to integrate for reasons related to the market structure, the characteristics of technology, the stage of maturity of the industry, and firm-specific factors. Given that integration involves both benefits and costs the decision may turn out to be firm-specific even within the same industry and will be carried out up to the point at which its costs outweigh its benefits.

The scope of empirical analysis in this field is very wide given the diversity of cases and the possibilities that vertical integration may bring about. The following chapter analyses the existing empirical evidence with particular attention to the case of the oil industry.

2. EVIDENCE

While there exists a large body of theoretical studies that analyse the issue of vertical integration (for reviews see Perry (1989), Warren-Boulton (1978), Casson (1984)), empirical research has not kept the same pace. Some of the earliest attempts to explain the reasons and the effects of vertical integration were made in case studies. However, a measurement of the impact of vertical integration on company performance has been made in a relatively small number of studies. Those aiming at quantifying this impact are of two types: inter-industry and single industry studies.

Inter-Industry Studies

Early studies tried to determine the relationship between integration and a host of other variables such as average firm size, concentration and firm growth (e.g. Adelman (1955), Gort (1962) and Tucker and Wilder (1977)). These studies usually lacked a theoretical backing for these relationships, and the purpose was the discovery of some stylized facts rather than the direct test of a particular hypothesis.

In spite of the popularity of the structure-conduct-performance (SCP) paradigm in the 1960s and 1970s, and its emphasis on empirical analysis, very few of the abundant empirical studies tackled the issue of vertical integration. Indeed the famous review by Weiss (1971) on SCP studies has only a handful of references to studies using some measure of diversification at the firm level as an explanatory variable (Broadman (1981)).

The debate on firm differences brought forward by the market-power-efficiency debate on concentration (see Schmalensee (1989)) recognized that the role of vertical integration in the exercise of market power should be resolved empirically. Martin (1986) focuses on both the causes and the consequences of integration in his empirical study of 288 industries in the USA. His premise, given the small numbers bargaining problem implicit in the transactions cost approach, is that concentration leads to efforts to integrate but in the long run vertical integration can lead to increases in concentration. His results confirm that fewness and sales growth affect integration directly as predicted by the transactions cost approach although the impact on profitability is mixed.

In the same vein Levy (1985), using Adelman's (1955) measure of vertical integation, relied on the industry as the basis of his analysis to test hypotheses from the transactions cost approach to integration. His results back these hypotheses, especially the relationship between fewness of firms, internal costs and unanticipated events. In other words, small number bargaining problems, internal limits to integration and uncertainty are reasons to follow an integration policy. The same success in relating integration to fewness is found by Caves and Bradburd (1988). Concentration in both supplying and buying-industry are correlated to integration as are measures of supplying and buying-industry expenditure on research and development (both measures of the specificity of investment).

The importance of the transactions cost approach to integration also emerges from a study of vertical mergers by Spiller (1985). The gains from mergers are calculated using stock market data and Spiller finds that they are directly related to the distance between vertically related plants, a measure of asset specificity in transactions.

An important result of inter-industry studies is that the structure-conduct-performance relationships emerge very strongly in some industries but not in others. Levy (1985) and Martin (1986) find that the strength of the relationship differs by industry (e.g. being strong in food manufacturing, unimportant in iron and steel) or in other words, the manufacturing sector is not homogeneous. This conclusion lends strong support to analytical studies of a single industry.

Studies of a Single Industry

Transaction costs considerations also play an important role in studies of a single industry. Stuckey (1983) for example, finds that the high transport cost of bauxite, the economies of scale of refining and the heterogeneity of bauxite and alumina combine to induce aluminium producers to integrate backwards. For the aluminium and tin industries Hennart (1988) confirms the same results showing the industry as a typical example of vertical integration undertaken for technological and transaction costs reasons.

Studies of a single industry mainly concern oil. The reason for this popularity is that the degree of vertical integration in oil perceived by the American authorities and its alleged association with market power have prompted various pieces of legislation. Teece (1976) finds few reasons to believe that the industry is oligopolistic in nature and claims that the degree of integration typically found is a reflection of transaction costs considerations. In particular, asset specificity in refining and transportation account for the fact that many refiners integrate backwards into production and forward into transportation. While Teece does not provide strong quantitative evidence of transaction costs considerations, Mitchell (1976) and Rusin and Siemon (1979) give backing to the idea that supply uncertainty is a reason for integration. In their models the dependent variable is either a measure of the cost of raising capital (Rusin and Siemon), or the Standard and Poor's rating (Mitchell). The result of Mitchell's estimations is a positive effect between his uncertainty proxy and a self-sufficiency measure but he points out the simplicity of the estimates. Rusin and Siemon on the other hand build a sophisticated measure of integration and as part of a simple model find a positive relationship with the measure purporting to proxy uncertainty. Uncertainty and integration occupy a prominent space in the reasons advanced by the industry to justify integration as a non-market power strategy.[7] To corroborate this point Levin (1981) fails to find a direct relationship between backward integration and the level of profits but a tenuous one emerges when profit variability is correlated with integration.

The result emerges more subtly in a study by Armour and Teece (1980) where it is found that returns to R&D can be shared among stages, and is therefore related to integration. R&D is another instance of capital specific investment, and as such constitutes part of the explanation of the transactions cost approach. The original idea comes from McLean and Haigh (1954) who argue that R&D may be more productive in the integrated firm since inter-segment spillovers in new knowledge can be internalized.

Uncertainty is a different reason for integration than those predicted by the transactions cost approach.[8] As explained earlier uncertainty as a reason for integration arises from a market imperfection and not from demand and input cost shocks that may characterize an industry. However, integration may reduce the variability in total profits when profit variability in two stages of the industry are negatively correlated. This is the result found for the oil industry by McLean and Haigh (1954) where refinery and upstream margins are negatively correlated.

The quantification of the costs of integration is only done in a study by Al-Obaidan and Scully (1993). The costs in terms of technical efficiency in highly integrated refiners is a reduction in efficiency of 32 per cent. This is the cost of circumventing opportunism and foreclosure risks while being rewarded by a reduction in risk of 29 per cent.

All empirical studies with the exception of Al-Obaidan and Scully highlight only the benefits of integration. Prevalent among these studies is a finding of risk reductionwhich has been interpreted as evidence in support of the transactions cost approach. Other studies point to the larger profits

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[7] Buzzell (1983) for example mentions the reasons given by Dupont for the acquisition of Conoco in 1981 were the reduction to the exposure to price fluctuations faced with the 1970's oil shocks. However, it is difficult to believe that the shocks were completely random and the reason must be some sort of imperfection in the market that integration would presumably avoid (Perry (1989)).

[8] Levin (1981) argues that security of supply means savings in the costs of petroleum refining, savings in transaction costs and the reduction of risk. The two first reasons are legitimate from the point of view of welfare. The third we argue is legitimate if it is the result of a market imperfection and not variations in demand conditions.

made by integrated companies.[9] However, if there were only benefits found we would expect companies to integrate without bounds and a single "equilibrium" level of integration would be observed in the industry. This stands in sharp contrast with observed differences in the levels of integration of companies in an industry however narrowly defined. Also, the levels of integration change over time, but this time dependency of the estimates is only explored by Levin (1981). His results show a difference between the period 1948-57 and 1958-72: prior to the Suez crisis the terms of oil concessions in the Middle East and Latin America are found to be favourable to the companies and as a result profits differ in both periods.

The following chapter discusses the measures of integration used in the literature and introduces those used in this paper.

[9] See a report cited in *Petroleum Intelligence Weekly* December 5, 1994, and the study of intra-industry structure of Broadman (1981).

3. MEASURES OF VERTICAL INTEGRATION

A firm can be defined as vertically integrated if it encompasses two single production processes in which either:

> (1) the *entire* output of the "upstream" process is employed as *part or all* the quantity of one intermediate input into the "downstream" process, or (2) the *entire* quantity of one intermediate input into the "downstream" process is obtained from *part or all* of the output of the "upstream" process. (Perry (1989) pp. 185) (italics in the original)'

The definition implies contiguous stages (i.e. no intermediate processing) and the elimination of market exchanges. In addition to these features, the internal transactions refer to physical and not monetary values. The ideal measure of vertical integration should fulfill these requirements.

Ideally one would like to construct a single measure of integration that encapsulates every stage of the industry, but this would presumably lead to a loss of information (Martin (1986)). With the data available in this study two distinct single measures of integration could be constructed. One measure enumerates the different stages of production in which the firm is involved, and would classify companies accordingly.[10] A second measure uses Adelman's (1955) ratio of value added to sales. However, it is well known that this measure is not symmetric according to the stage of production, being greater for stages closer to the upstream. Furthermore, due to its inherent correlation with profitability and efficiency, the measure has little empirical value in a study like the one pursued here.

The oil industry has the advantage of having physical (i.e. quantity based) measures of production at every stage that once combined could produce a single measure of integration. This is done for example, by Rusin and Newport (1978) for a large sample of American companies in the years 1971 to 1975 where the physical measures are aggregated by using value added at every stage as weights. This approach is very demanding on data requirements and one of its drawbacks is its inability to identify economies of contiguity between stages. In our case, the absence of data on value added by stage leads us to construct a measure of integration by number of stages.

Consider the whole petroleum activity as a process taking crude oil all the way to the final consumer. The activity can be represented by:

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[10] The oil industry is usually classified into the stages of exploration and production, refining, transportation, and marketing. This discrete measure of integration is used by Armour and Teece (1980) and can also be computed for our sample.

$$P \rightarrow T^c \rightarrow R \rightarrow T^p \rightarrow M \rightarrow C$$

where P is exploration and production of crude, T^c is transportation of crude in either barges, tankers or by pipeline, R is the refining of the crude and what will constitute the fulcrum of the industry. T^p is transportation of refined products, and M is the marketing of refined products, while C is consumption. Taking R as the core of the industry all measures of vertical integration used in this study are constructed around the refining activity.

Vertical integration is by definition the undertaking of activities at more than one stage of the production process. Whether a firm decides to enter one stage or not usually depends on whether the firm chooses to obviate the market. This definition of integration derives from that of the firm as a collection of activities aimed at bypassing the market (Coase (1937)). In line with this definition, adopted by most analysts, our measures of vertical integration will refer to activities at each of the four stages (i.e. P, R, M and $T=T^c+T^p$). The variables at each stage will be: (1) production, thousand barrels produced per day; (2) transportation of crude, transportation by pipeline as data is only available in a meaningful form for this means of transport which, anyhow, constitutes more than 50 per cent of the amount of crude transported in the USA during the period (*API Basic Petroleum Data Book* Vol XV No 1 1995); (3) refining, refinery runs, which is a measure of the amount of transactions the firm has chosen to involve in rather than those it could involve itself in (the latter represented by refining capacity, sometimes used as a measure in this context); (4) transportation of products, only refers to pipelines (5) finally, marketing is the number of barrels sold per day (a measure of wholesale not retail sales).

In line with the definition of integration and the definition of refining as the core of the business the measures proposed are:

1-. A measure of integration between production and refining defined as:

$$IPR_{it}=\left|\frac{P_{it}}{R_{it}+P_{it}}-0.5\right|, \tag{1}$$

where P is crude and NGL production for firm i in period t, and R is refinery runs. The first term in the absolute value operator is bound between 0 and 1, where 0 refers to a firm engaged only in refining, and 1 to a firm engaged only in production. A value of 0.5 refers to a firm in both refining and production that uses the market neither for selling nor buying its input. By giving equal weight to both activities a firm selling, say 90 per cent of its input, is presumed to be as integrated as one buying 90 per cent. The use of the absolute value operator and the subtraction of 0.5 from the ratio is made in order to have a linear measure of integration. Hence, the values of the final measure of integration lie between 0 and 0.5. The latter corresponds to both a non-producing refiner and a non-refining producer, while the former corresponds to a totally integrated oil company. The reason for the additional correction to the ratio is to incorporate companies involved in only one of the production stages (i.e. only refining or only producing).Our measure is different from the normally used backward measure of integration (self-sufficiency ratio: the ratio between production and either refinery runs or refining capacity) as we want to give equal weight to backward and forward integration.[11]

2-. The second measure of integration takes into account the marketing of oil products by the company and is expressed as:

$$IRM_{it} = \left| \frac{M_{it}}{M_{it}+R_{it}} - 0.5 \right|, \qquad (2)$$

where M is barrels of petroleum product sold by the refiner. The comments made in the previous paragraph apply to this measure but the sample here consists of refiners or marketers only. This is a measure of integration between refining and marketing.

3-. The third and fourth measures of integration relate to transportation. Barrels of crude oil and petroleum products transported by pipeline are used to build measures of integration between refining and crude and products transportation:

$$ICTR_{it} = \left| \frac{T^{c}_{it}}{T^{c}_{it}+R_{it}} - 0.5 \right|; \qquad IRPT_{it} = \left| \frac{T^{p}_{it}}{T^{p}_{it}+R_{it}} - 0.5 \right|, \qquad (3)$$

where T^c and T^p are barrels of crude and product transported by pipeline.

The measures of integration are computed for all the firms in the sample. The data for production, refinery runs and products sold by refiners come from company reports, *Financial Times Oil and Gas International Yearbook* (1976-1994), and various issues of the *Oil and Gas Journal (OGJ 300, 400)*. The data used to construct the integration measures in transportation comes from the

[11] It also differs from the measure used by Levin (1981) which corresponds to the first expression in the absolute value operator. The reason is that his measure is not monotonic with respect to integration.

report *Oil and Gas Journal (Pipeline Economics)* which identifies the amounts of crude and products transported by pipeline. However, pipelines are jointly owned by companies in the sample, so the ownership structure of the pipelines was traced and the volume transported was divided on a pro-rata basis.

Our measures of integration focus on the use or avoidance of the market and not on some financial or monetary criteria. One advantage of these is that they are based on clearly defined stages where successive and separate production activities are observed. Furthermore, physical measures allow us to compare integration between stages in a distinctly clear manner. The disadvantages arise from the treatment of spot markets trade in the same way as any other type of trade contracts. This distinction is particularly critical for the measure of integration into marketing. We have implicitly assumed that the refiner only integrates into wholesale distribution without further integration into retailing where the issue of moral hazard is particularly interesting and where some of the more recent instances of de-integration have been observed.[12]

[12] For a theoretical and empirical analysis of the UK see Cafarra (1994). For recent instances of de-integration in retailing witness Exxon sales of petrol stations in Europe and Arco's decision to concentrate in regions to the west of the Mississippi river only.

4. SAMPLE

The sample in this study consists of American companies whose stocks are traded in the New York Stock Exchange for which relevant data are available in DATASTREAM©. The companies are defined as oil companies if they are listed in either the *Financial Times Oil and Gas International Year Book* (1974-1994) or the *U.S.A. Oil Industry Directory* (1983-1994). The sample period (1974-1993) is that for which information is available in DATASTREAM.

Their sample includes information for 234 companies (corresponding to 3,223 observations). Hence the data constitutes an unbalanced panel as the number of observations vary by company. Information concerning production stages was only available for 209 companies (2,910 observations). Of all the companies 43 per cent have 19 observations with the remaining companies distributed between 1 and 18 observations.

The companies were identified by stages of production and physical output in each stage. Classifying the companies by stage of production reveals that at least 193 (or 93 per cent) of them are involved in exploration and production (see Table 4.1), while only 17 per cent are involved in refining.

Table 4.1 Companies by Stage of Production

Stage	**Companies**	**Observations**	**per cent**
Production	193	2647	92.3
Refining	36	599	17.2
Transportation	48	790	22.9
Marketing	54	877	25.8

Source: See text

Although there are many interesting features in the data available, we shall only concentrate on those pertaining to the degree of vertical integration. The following section explores in detail the various patterns of integration according to the qualitative and the quantitative measures described above.

Patterns of Integration

In a world where differences in companies' characteristics are not important we would expect firms to pursue very similar integration strategies. However, one of the features of the companies included in our database is the large dispersion in the measures of integration.

Qualitative Measures. We computed first qualitative measures of integration. We regard as unintegrated all those companies involved in only one stage of the industry, semi-integrated, companies involved in 2 or 3 stages; and fully integrated those involved in four stages of the industry. In our sample of companies at least 67 per cent are regarded as non-integrated and only 11 per cent are fully integrated (Table 4.2).[13]

Table 4.2 Companies by Degree of Integration

Degree	Companies	Observations	per cent
Non-integrated	142	1898	67.9
Semi-Integrated	44	578	21.0
Fully Integrated	23	434	11.0

Source: As in Table 4.1.

One of the limitations of the qualitative measure of integration is that given the few instances in which a company enters a new stage of production its degree of integration is unchanged. In fact changes in the number of stages in our sample are observed in only four instances.[14] This is not to say that companies do not divest or acquire some assets, but these transactions are made *within* the stages the companies are already involved in. Qualitative measures fail to capture deepening of integration within the stages and as a result the degree of integration of a company using this measure is invariant over time. By failing to respond to changes in the time dimension the measures could proxy intrinsic firm differences that may not be related to integration.[15]

[13] The sample of companies and their degree of integration is presented in Appendix II.

[14] The companies are Apache in 1987, which moved into transportation, Kaneb in 1989, which divested its production activities, Mapco in 1982, which divested its refining operations, and Valero in 1987 which concentrated only in production. These apart from Gulf and Getty which were taken over by Chevron and Texaco in 1984 and 1983 respectively.

[15] In this respect it comes as a surprise that the study by Al-Obaidan and Scully (1993) decides to use dummies according to the degree of backward integration when they already have the physical measures. Their defence comes

Physical Measures. Despite their drawbacks the physical measures of integration described in Chapter 3 have powerful features that allow us to treat forward and backward measures symmetrically.

As already mentioned, if firms were not very different and if the advantages of integration were overwhelming, we would expect to see a concentration of companies towards the left of the distribution (i.e. towards 0 where integration is complete). Figures 4.1 and 4.2 present the distribution of the four physical measures of integration described in Chapter 3.

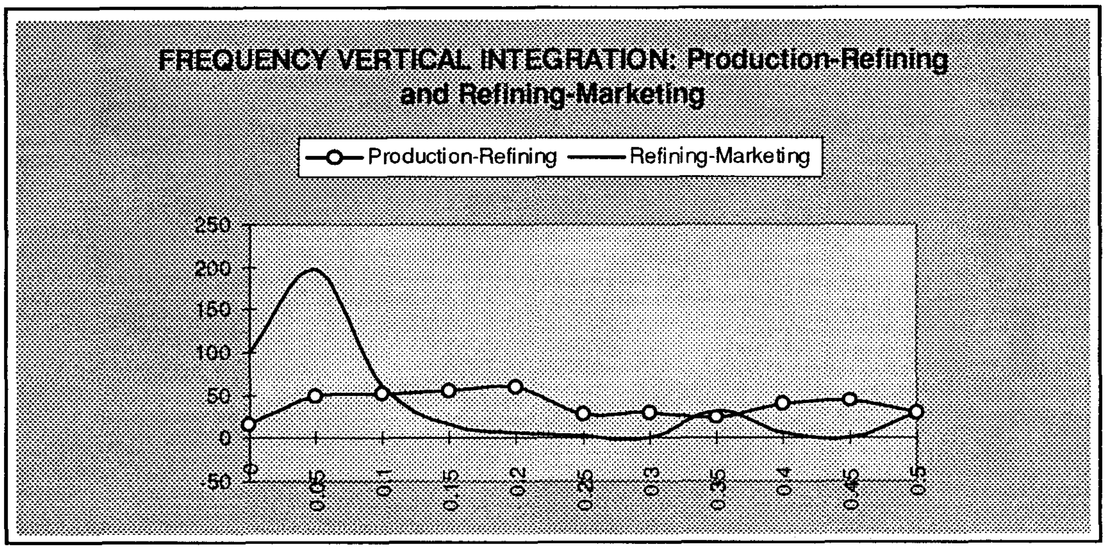

Figure 4.1

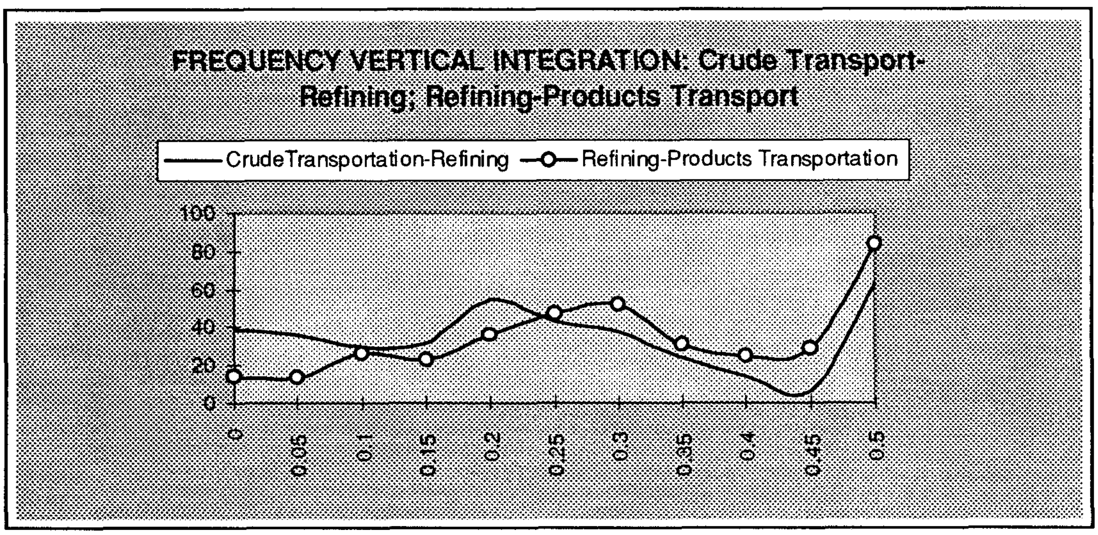

Figure 4.2

from the fact that their sample contains refiners and producers only.

The production-refining measure does not reveal any concentration towards the 0 mark. Observations are spread along the spectrum although the greater weight is found between 0.05 and 0.2 (skewness is very low to the left being only -0.054). By contrast, the refining-marketing measure is highly concentrated towards the left with many companies being either fully integrated or having scant recourse to the outside market (skewness=-2.10). Both measures of integration in transportation tell a similar story. They both have two peaks in the middle and at the non-integrated extreme. However, the crude measure has greater weight towards the left side (integrated with skewness=-0.183), and the products measure has that excess weight towards the right (non-integrated with skewness= 0.443).

Of all measures the one with greater dispersion is the measure between production and refining (standard deviation σ=0.163), followed by the measure between crude transport and refining (σ=0.15), and further down product transport and marketing (σ=0.13 and σ=0.11 respectively).

As opposed to the qualitative measures the physical measures change over the period. Figure 4.3 presents annual averages of the four physical measures of integration.[16]

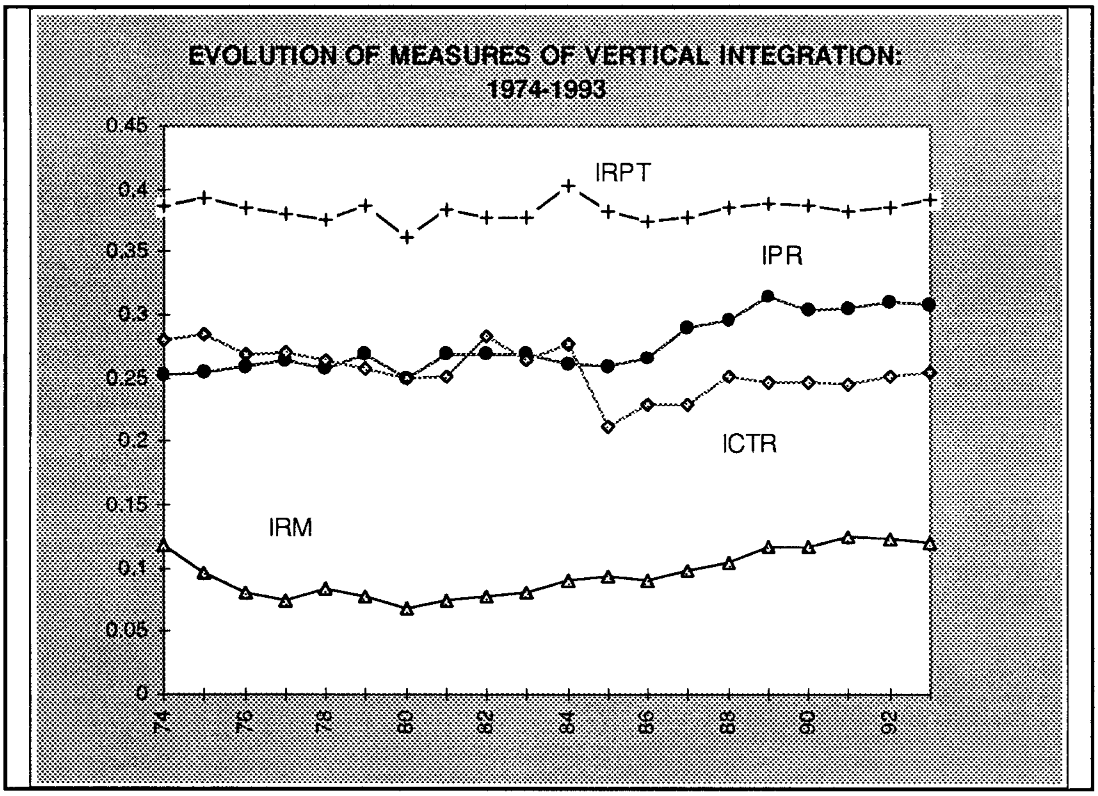

Figure 4.3

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[16] The measures are not weighted by, say size of company, as we would like to give each company a weight of one. The reason is that when analysing firm differences the decision to integrate is individual.

Most measures do not show large variations over time with perhaps the exception of the IRM index. This index shows integration increasing during the 1970s and falling steadily thereafter, but the end value is not much different from the initial one (the largest annual change is -8 per cent). Similarly, the production/refining measure is almost constant throughout: a tenuous and steady increase although the difference between the highest and lowest value is only 25 per cent and the largest annual change is only 4.7 per cent. The only discernible pattern is a rise in the measure (a fall in integration) after 1986. The measures of integration in transportation have different evolutions. Integration in crude transport only has a large fall in 1985 (11 per cent) but subsequently recovers. In contrast, product transport has an erratic behaviour with a downward trend in the seventies and irregular increases after the year 1980.

To assess the importance of inter-firm differences relative to intra-firm differences we can divide the overall variance in the measures between cross-sectional and firm-specific variance. The total variance of a variable, say X, is:

$$\sigma^2 = \frac{1}{NT} \sum_{i=1}^{N} \sum_{t=1}^{T} (X_{it} - \bar{X})^2,$$

where T is the total number of periods, N the total number of firms, and $\bar{X}$ is the mean. The total sample variation can be decomposed in the sum of within and across firm variation:

$$\sigma^2 = \frac{1}{N} \sum_i \sigma_i^2 + \bar{\sigma}^2,$$

where:

$$\sigma_i^2 \equiv \frac{1}{T} \sum_t (X_{it} - \bar{X}_i)^2,$$

is the firm-specific variance and,

$$\bar{\sigma}^2 \equiv \frac{1}{N} \sum_i (\bar{X}_i - \bar{X})^2,$$

is the variance across firms of the firm-average of X. The first term is the average over firms of the firm-specific variance, and gives a measure of the time variation of X relative to the second which is a measure of cross-sectional variation. The difference between the cross-sectional variation and the firm-specific variation is an estimate of the *true* variance of companies (Swamy (1970)). The ratio of the cross sectional variation as a percentage of total variation in the integration measures is presented in Figure 4.4, for companies included in *at least one* stage and *both* stages.

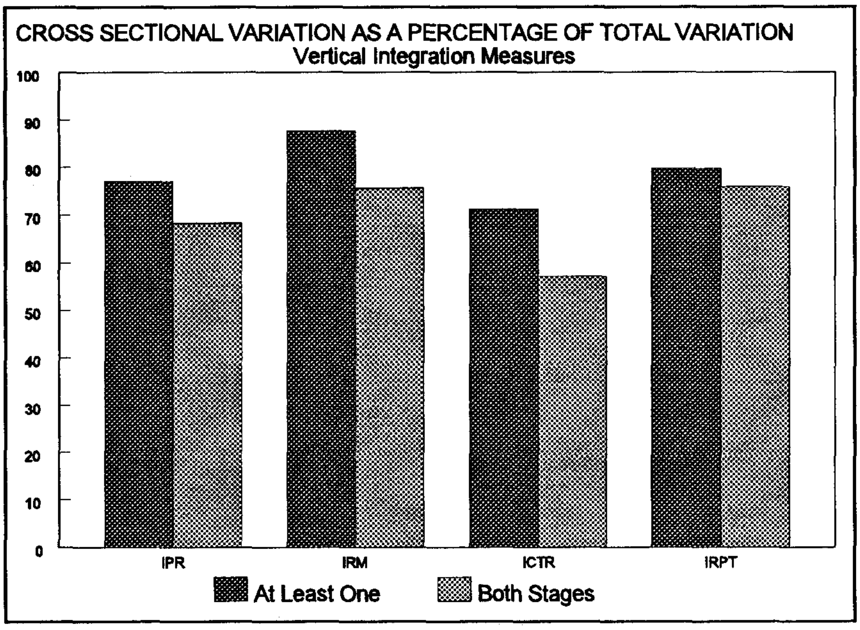

Figure 4.4

It is seen that in all cases, the cross sectional variation exceeds the time variation, in other words firm differences exceed sample error. The share of cross sectional variance of firms involved in at least one stage always exceeds those in both stages because very few companies move into new stages and as a result the bulk of the variation in those companies is inter-firm. All this implies that firms do not change their integration strategy much over time and as a result most of the variation comes from differences in the degree of integration of firms.

Using a similar measure of integration, Levin (1981) shows that there is no discernible pattern of integration in the period 1948-1972. He observes a wide degree of variation in integration even in the largest firms and, despite considerable movement in the degree of self sufficiency, no systematic trend toward greater integration. This is also corroborated by the evidence cited in McLean and Haigh (1954) concerning the interwar period. As Levin stresses, there are only two periods showing a steady movement towards integration: during the war years, and before the divestiture of Standard Oil in 1911. The first period was characterized by price and allocation controls, and thus no market clearing, and the second by monopsony power where the upstream surplus can be converted into profit by backward integration by the monopsonist (Perry (1978b)).

It is believed that in both periods markets did not operate smoothly and as a result transaction costs could be large.

It is no use showing the large degree of inter-firm variation if they cannot be related to firm performance and firm characteristics. The following chapter presents descriptive evidence of differences in vertical integration between firms and how these can be related to certain firm characteristics.

Firm Differences

To provide evidence on firm differences by their degree of integration we compare statistical differences in two measures commonly believed to be associated with integration. The first measure is size, defined as the log of total assets, and the second is a measure of profitability, the after-tax rate of return on total assets.[17]

To compare statistically these measures we use an analysis of variance and divide companies according to their degree of vertical integration. The qualitative measure was described above, and the cutoff points of the physical measures of integration are defined as:

$0.000 \leq$ Full-Integration < 0.125
$0.125 \leq$ Semi-Integration < 0.250
$0.250 \leq$ Low-Integration.

The coefficients of the analysis of variance are presented in Table 4.3 together with F statistics. Although t-statistics for the individual coefficients are not presented, they were all different from zero at 99 per cent level of significance, which reassures us that the differences have a statistical meaning.

The qualitative measures show that in terms of size fully integrated companies are on average 21 per cent larger than semi-integrated which are in turn at least 10 per cent larger than non-integrated companies. This is not surprising as the qualitative measure treats integration as the addition of a stage. In contrast, the physical measures find that the largest firms are those regarded as semi-integrated.[18] More surprising is that by the same measure non-integrated companies

[17] After-tax return is defined as the sum of net income and interest payments.

[18] This holds for all comparisons with the exception of the refining-marketing measures for firms in both stages.

appear to be larger than fully-integrated companies. The result is to be treated with caution as this only holds when companies in at least one stage are included but is reversed when analysing companies in both stages. A similar result is found if the analysis is made in continuous form. Regressing integration on size using a quadratic function shows that size increases with integration at a decreasing rate, reaching its peak in the range we have called semi-integrated. This holds for companies included in both stages.

Table 4.3 Firm Differences in Size and Profitability by Degree of Vertical Integration

Integration	Low	Semi	Full	F test	Low	Semi	Full	F test
				Size				
Qualitative	11.11	12.31	14.88	28511				
Physical	At Least One Stage				Both Stages			
IPR	11.56	15.23	13.27	23382	14.46	15.23	14.87	8192
IRM	12.33	14.03	11.82	20566	14.84	14.07	14.95	10145
ICTR	13.01	15.71	11.46	23856	14.21	15.71	14.39	11195
IRPT	13.35	15.55	11.36	24241	14.46	15.55	14.46	10487
				Profitability				
Qualitative	0.79	1.51	1.57	315.6				
Physical	At Least One Stage				Both Stages			
IPR	0.96	1.56	1.59	291.3	1.85	1.56	1.24	542.8
IRM	0.91	1.77	1.73	307.1	1.16	1.81	1.78	482.4
ICTR	1.73	1.67	0.86	318.8	1.96	1.67	1.54	489.1
IRPT	1.81	1.51	0.81	377.4	2.04	1.51	1.19	591.6

Source: See text.

Note: All tests of significance are different from zero at 99 per cent.

Rusin and Newport (1978) find that the relationship between integration and size in the oil sector is positive but not particularly strong. They regress their measure of integration on refinery runs as a proxy for size. Our results would show the same monotonic relationship had the quadratic term been excluded, but this coefficient proves significantly different from zero in all cases with the exception of the refining-marketing measure. A very strong relationship between size and integration is found by McLean and Haigh (1954 pp. 49): in 1950 only three non-integrated refiners, out of 160 companies in the sample, had capacities in excess of 50,000 barrels per day.

The analysis of profitability is less clear cut. On the one hand, the discrete (qualitative) measure of integration shows the result found in a recent study where fully-integrated firms outperform all other companies in the industry.[19] However, the results are difficult to interpret using the physical measures. If the sample is limited to companies in at least one stage only the ranking of

[19] The report is referenced in *Petroleum Intelligence Weekly* December 5, 1994.

the two transportation measures coincide; the production-refining measure ranks companies as the discrete measure, whereas the IRM index places the semi-integrated group at the top of the profitability distribution.

When the sample consists of companies participating in both stages instead of at least one stage the results using the IPR are reversed. The ranking using the IRM and transportation indices are identical as the samples are not much different. Using a continuous measure did not improve matters much. On the one hand, there is a positive relationship between integration and profitability for companies involved in at least one stage, although significant only for the IPR measure; and on the other hand there is a negative and significant relationship between integration and profitability in all, except the IRM, samples using firms in both stages.

The evidence on profitability and integration found in the literature is also mixed. Levin (1981) reports no relationship between the two, while Broadman (1981) reports a strong positive relationship. In the results presented here, the rankings depend on the measure of integration and the sample used. The first reason for our inability to establish a relationship, apart from the crudeness of the measure of profitability, is that no full model estimation has yet been attempted. Another reason for the differences in the rankings is the fact that profitability in upstream companies is heavily determined by geological and geographical considerations that may not be related to the degree of vertical integration. Including companies that are involved in only exploration and production, the bulk of the at-least-one-stage-IPR sample, affects the results. With this last caveat in mind the results on profitability using three of the four measures are identical, the only anomaly coming from the use of the integration index between refining and marketing.

In spite of the fact that the measure of profitability is very crude, some of the differences in vertical integration are found to be related to observable firm differences. The following chapters explain the empirical model used to analyse firm performance.

5. MODEL

The panel data of companies described in the previous chapter is used to test differences in firm performance according to the degree of vertical integration. Performance is defined as efficiency in production in the sense of using factor inputs optimally. In a nutshell, although most structure-conduct-performance studies focus on profitability as an indicator of performance, we take a more direct approach and regard productive efficiency as a measure of performance.[20]

The model used to analyse firm efficiency following the traditional approach, is the production function. The model uses a Cobb-Douglas production function with variable returns to scale, although the Cobb-Douglas and returns to scale assumptions are relaxed. Other control variables, as well as the degree of vertical integration, are included on the right hand side. The reason for including vertical integration on the right hand side, instead of deriving a measure of efficiency and then correlating it to the degree of integration, is because, within the production function framework, once inputs are controlled for an impact on production is nothing but an impact on the efficiency of production.[21] The full model takes the following form:

$$y_{it}=\lambda_i+\gamma y_{it-1}+\alpha l_{it}+\beta k_{it}+\delta VI_{it}+\phi_1 s_{it}+\phi_2 b_{it}+\phi_3 p_{it}+\rho u_t+\omega t_t+\epsilon_{it}\ , \qquad (4)$$

y is log of output, or value added, l is labour input, k capital, s is a measure of competition, b is an index of leverage, p an index of the firm's relative performance *vis à vis* other competitors, u an index of cyclical factors, λ are the firm effects, i the identity of the firm and t the time period which when used as an independent variable becomes a trend. ϵ is the error term with variance σ^2 and mean 0.[22] VI is the physical measure of vertical integration which according to the sample used is defined as:

$$\delta VI_{it}=\delta_1 IPR_{it}+\delta_2 IRM_{it}+\delta_3 ICTR_{it}+\delta_4 IRPT_{it} \qquad (5)$$

---

[20] The rank correlation between profitability and efficiency does not need to be perfect under imperfect competition.

[21] Al-Obaidan and Scully (1993) prefer to derive the measures of efficiency and then correlate them with integration. This is because their measure is qualitative. A problem with this methodology is that for the two-step procedure to be accurate it must be assumed that the independent variables are not correlated with efficiency (Schmidt (1985-6)).

[22] The assumption of constant variance is tested and the model expanded as discussed below.

where the integration variables are those described before.

The production function (4) is dynamic by nature and for this reason we include output, or value added, lagged one period to reflect output dynamics. The intuitive reason for doing this is because there are adjustment lags in labour or capital to enter production fully. As a result output is not at its maximum during that period. Put differently, there are adjustment costs in the production process.

The firm-specific effects λ_i capture all unobserved company specific factors which influence productivity. The introduction of firm effects is fundamental as managerial and idiosyncratic differences are very important and constitute one of the advantages in the estimation of models using panel data.[23] Year-specific effects are not introduced directly but in the form of a time trend. The reason is because the cyclical factor, u_t is time specific which accounts for the importance of demand pressures that allow improvements in efficiency in the short run.

The competition variable s reflects the importance of market structure for the level of productivity. The level of productivity is affected by competition by the slack argument made by the structure-conduct-performance paradigm (see Martin (1993)). Slack is associated with the effort of managers and workers, or in other words, factors relating to the organisation of production.[24] It is presumed that lower competitive pressure encourages slack and therefore reduces productivity. Related to the issue of competitive pressure is the question of competition by comparison (Vickers (1993)): if rival firms in the sector are more efficient, there is pressure on the company to improve its efficiency.

The role of leverage on firm productivity is related to the "discipline of debt" hypothesis (Jensen (1988)). The higher the leverage of the company, the lower is the free cash-flow that can be used by managers to engage in activities that may reduce shareholders' wealth. Subsequently, the greater the debt exposure the greater is the efficiency level of the company.

To complete the model we can recapitulate the presumed advantages of vertical integration on firm productivity. The market power hypotheses lead us to believe that efficiency should be positively related to integration but the diseconomies of both size and specialization reduce it. The

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[23] On the importance of firm effects see Schmalensee (1985), Amel and Froeb (1991) and Kessides (1990).

[24] On the empirical evidence of the effects of competition on productivity levels see Nickell (1993), Nickell, Wadhani and Hall (1991) and Barrera (1994).

combination of these two factors makes the resolution of the hypotheses an empirical matter.

The discussion in Chapter 1 suggests that vertical integration will not only affect the level but also the variability of efficiency. In fact the empirical results concerning the impact of vertical integration in the oil industry on firm performance have stressed the reduction of risk, measured as: (a) profit variability (Levin (1981)), (b) the cost of raising capital (Rusin and Siemon (1979)), (c) Standard and Poor's common stock rating (Mitchell (1976)), and (d) scale efficiency (Al-Obaidan and Scully (1993)). Our innovation here, is to test both hypotheses concurrently and estimate the model accordingly.

It is hypothesized that the variance of the error term ϵ_{it} , σ^2 is itself a function of vertical integration:

$$\sigma_{it}^2 = \theta_0 + \theta_1 VI_{it} + \eta_{it} , \qquad (6)$$

in which case as explained below, the estimates of (4) will have to be corrected accordingly.

6. DEFINITION OF VARIABLES

The model in (4) uses as dependent variable (*y*) either sales or value added. The problem with sales is that we have no information on materials used and in the case of refining companies where the main input is so important there is no provision made for efficiency in the use of crude oil. We try to deal with this objection by using a proxy measure of value added. The problem is that the measure of value added is not very meaningful. We subtract the cost of sales from the sum of wages and sales as our measure of value added. Sales are deflated by the annual wholesale price index for the US oil industry (OECD, *Industrial Structure* (1980-1995)), and the cost of sales plus wages is deflated by an index of material prices for the oil industry (*US President Report 1994*). Labour is defined as total number of employees, and capital is constructed as follows:

$$k_{it} = \text{Fixed Assets}_{it} \times \left(\frac{P_t}{P_{t-a}}\right), \tag{7}$$

where P is an industry-specific investment deflator, and a is the average life of an asset (6 years). The measure expresses the historic cost of the asset (Gross Fixed Assets) as the current replacement cost by multiplying it by the relative price of assets today to 6 years before.[25]

The measure of competition used is the share of each company in industry sales. As the panel is not only unbalanced but also does not include all US producers, the measure is constructed as a proxy. The calculation procedure is described in Appendix I. The measure of relative competitiveness is computed as follows:

$$p_{it} = \frac{1}{N-1}\sum_{j \neq i}^{N-1} \pi_{jt} - \pi_{it}, \tag{8}$$

where π is the after-tax profit margin: the ratio of net profit and total sales. The measure represents how much firm *i*'s profit margin deviates from all other firms' profit margin.

The leverage measure used, b, is the borrowing ratio defined as the sum of total loan capital and borrowing repayable during one year over total equity capital and reserves plus deferred tax less

25 Alternative and more appropriate definitions of the capital stock, could not be computed because of data availability.

goodwill plus the numerator. The measure should be closely related to the amount of free cash flow available for decision making.

Industry growth rates are traditionally used as measures of cyclicality, or demand pressure, however the oil industry has a superior measure of demand pressure in the index of utilised refining capacity for the American market (API *Basic Petroleum Data Book* Vol XV No 1 1995). The measure is industry-wide and is therefore common to all companies in the sample.

7. ESTIMATION

To account for firm specific effects (λ_i) the estimation procedure is within-groups. Within- groups estimation is equivalent to fitting a separate intercept for each company or, by the algebra of least squares, expressing each observation as the deviation from its individual mean. In other words the within-groups operator expresses the variable x_{it} as:

$$W(x_{it})=x_{it}-\bar{x}_i, \quad \bar{x}_i=\frac{1}{T}\sum_{t=1}^{T} x_{it} \ . \tag{9}$$

Applying the within-groups operator to equation (4) yields:

$$W(y)=\gamma W(y_{-1})+\alpha W(l)+\beta W(k)+\delta W(VI)+\phi_1 W(s)+\phi_2 W(b)+\phi_3 W(p)+\rho W(u)+\omega W(t)+W(\epsilon) \ , \tag{10}$$

where by virtue of time invariance the firm effects are eliminated from the equation.

As mentioned above, the possibility that the variance of efficiency is related to vertical integration is assessed. The usual measure of variance is the squared product of the residuals ϵ which is not readily available. The reason is that the original residuals from equation (4) can only be derived by using the estimated parameters (the γ, α, β, δ,..) and the variables in levels (i.e. not those transformed by the within-groups operator). This produces an estimate of $u_{it}= \epsilon_{it}+\lambda_i$ and we have to subtract from it the estimates of λ_i to construct our variance measures. Firm-specific parameters are computed by regressing u_{it} on firm-specific dummies and using the squared residuals from that regression as the measures of variance and regressing them on *VI*:

$$\epsilon_{it}^2 = \theta_0+\theta_1 VI_{it}+\eta_{it} \ . \tag{11}$$

As one of the assumptions of the classical model is the assumption of constant variance, in case (11) proves significant the model in (10) suffers from heteroscedasticity. To correct for heteroscedasticity (11) is used to construct appropriate weights to estimates (10) (see Greene (1992) for example). The weights are equal to the predicted values of (11):

$$w_{it}=\frac{1}{\hat{\epsilon}_{it}^2}=\frac{1}{\hat{\sigma}_{it}^2} \ , \tag{12}$$

in which case firms with greater variance in efficiency have a lower weight in the estimation of (10). In case $\theta_1 > 0$, the variance falls with integration and more integrated companies are given a greater weight in (10).

Before presenting the estimates obtained by fitting these equations to the data, a word of warning is in order. Empirical industrial organization studies have long been criticized because of problems of endogeneity. In other words, the structure-conduct-performance paradigm, in its simpler versions, stated that market structure was exogenous and determined industry behaviour and therefore performance. The debate on efficiency *vs* market power provided an important objection to the paradigm. Classical industrial economics, with its emphasis on the industry, conjectured that the degree of concentration of the industry was a good indication of the probability of collusion and therefore of market power. Demsetz (1973) objected that more efficient companies tended to grow large and would increase their share in industry sales leading to a more concentrated market structure. This creates problems of endogeneity (left and right hand side variables being determined simultaneously) and generates biases in the estimates. Take for example the use of market share as a proxy of market power in an efficiency equation like the one above. By the Demsetz argument we would expect more productive firms to grow large and increase their share (left to right causation: positive coefficient on s) instead of market power causing slack (right to left causation: $\phi_1<0$). A similar argument could be made concerning the role of vertical integration in a productivity equation like the one estimated here. In that case, for example, could it be that once a certain level of efficiency is achieved the firm may find it profitable to undertake more diversified tasks? (i.e. that the causality be running the other way round).

This is the endogeneity problem that has plagued many industrial organization studies. One solution is to use simultaneous equation models (Geroski (1982)) which are data demanding or the use of instrumental variables. The second solution (Arellano and Bond (1991)) , relying on panel data, is to use lagged values of the variables provided the error structure is not autocorrelated. We have opted for an imperfect solution and have used lagged values of the firm-level variables as independent variables while modelling explicitly the error term. All firm-specific variables have been lagged one period, with the exception of market share lagged two periods (Nickell (1993)).

8. ESTIMATES

Before commenting on the estimates of the determinants of efficiency, a discussion on what type of efficiency we are measuring is necessary at this point. Fixed effects estimation, of which within groups is one, places a great emphasis on the time variation of the variables, *vis à vis*, say OLS or between units estimation. Due to the nature of the estimation (see equation (10)), deviations from the mean in the right hand side variables affect deviations in efficiency from the mean. This is closer to the concept of level rather than growth in efficiency, and therefore corresponds more to the organization of production and the optimal use of production inputs associated with the slack and coordination arguments referred to above.

The model (4) was estimated for all the following four samples:

Sample (1): Firms involved in E&P *and/or* refining,
Sample (2): Firms involved in E&P *and* refining,
Sample (3): Firms involved in E&P, refining and marketing,
Sample (4): Firms involved in E&P, refining, marketing and transportation.

The reason for giving greater emphasis to E&P rather than other stages of the industry, (i.e. the inclusion of sample (1)), is the fact that most companies are engaged in at least this stage of the industry, and also because firms engaged in only transportation or only marketing are very few.

Five different models were fitted to the four samples above. The models differ according to the dependent variable:

A). Models with firm sales as the dependent variable:

(1) Unweighted within-groups estimates of (10) with constant returns to scale in the production function (i.e. restricting $\alpha+\beta=1$);
(2) Weighted within-groups estimates of (10), using as weights the predicted residuals from (11) with constant returns to scale;
(3) As (2) but allowing constant returns to scale to be variable.

B). Models with firm value added as the dependent variable:

(4) Weighted within-groups estimates of (10), using as weights the predicted residuals from (11) with constant returns to scale;
(5) As (4) but allowing constant returns to scale to be variable.

Before presenting the estimates we must explain the decision to include companies engaged in only exploration and production or refining only. The underlying hypothesis in this paper is the belief that, given the intrinsic characteristics of the company, the firm performs a cost-benefit analysis when deciding its integration strategy. The fact that some companies have decided to specialize in a single stage of the industry should give us information concerning the specific advantages or costs of integration. In other words, the exclusion of the non-integrated companies from the analysis could bias the results in the direction of overstating the benefits of integration. The problem of including these companies, is that the overwhelming un-integrated companies are engaged in only exploration and production. Although this segment and refining are parts of the same industry, the two are very different activities requiring very different levels of investment, managerial capabilities, sunk costs and may be regarded as not belonging to the same narrowly defined industry. To strike a balance between the two positions, we have decided to conduct estimations including companies in only E&P but controlling for the influence of vertical integration on firm performance by interacting IPR_{it} (the measure of integration in production and refining) with a dummy variable e&p:

$$\text{e\&p}\quad \begin{cases} = 1 & \text{if company is engaged in only exploration and production,} \\ = 0 & \text{otherwise;} \end{cases}$$

in which case, the effect of integration for companies engaged in only E&P is found by adding the parameters of *IPR* and e&p in the estimates below.

Table 8.1 presents estimates of models (1) to (5) for samples (1) and (2). Table 8.2 presents the same models for samples (3) and (4). In the table, the values correspond to the coefficients, and the figures in square brackets refer to t-statistics. N×T is the total number of observations available for estimations, MSE is the mean standard error of the regression, RTS refers to returns to scale in the production function, F. F.E. correspond to F-tests of the importance of firm effects (the λ_i's above). R^2, the coefficient of determination and the correction for heteroscedasticity (or test of variance in efficiency and vertical integration), are presented at the bottom of the table. The t-ratios for the heteroscedasticity correction are White-heteroscedasticity-robust-t-ratios (White (1980)), as the regression (11) is heteroscedastic by construction (Greene (1992)).[26]

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[26] In the estimation of (11), only integration between production and refining turned out to be significant and for this reason it is the only integration variable included in the heteroscedasticity correction. The Cobb-Douglas hypothesis was also tested by means of higher powers on *l* and *k* but was rejected without much change to the estimates.

Table 8.1 Models of Company Efficiency: First and Second Samples

MODEL	(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)
SAMPLE	**E&P *and/or* Refining (1)**					**E&P *and* Refining (2)**				
D. Variable		**Sales**		**Value Added**			**Sales**		**Value Added**	
y_{it-1}	0.719*	0.713*	0.494*	0.358*	0.468*	0.552*	0.569*	0.903*	0.208*	0.496*
	[51.55]	[52.32]	[25.61]	[15.09]	[22.21]	[16.26]	[17.00]	[49.91]	[5.88]	[16.35]
l_{it}	0.866	0.848	0.327*	0.729	0.363*	0.629	0.639	0.023*	0.562	0.052*
			[15.61]		[15.67]			[1.842]		[2.682]
k_{it}	0.134*	0.152*	0.207*	0.271*	0.199*	0.371*	0.361*	0.064*	0.438*	0.355*
	[13.54]	[14.77]	[9.746]	[12.35]	[8.471]	[10.77]	[10.40]	[3.411]	[10.31]	[9.683]
s_{it-2}	-0.561*	-0.418	-0.041	-0.416	-0.061	-0.31*	-0.302*	-0.342*	-0.267*	-0.463*
	[-1.75]	[-1.43]	[-0.96]	[-1.38]	[-.086]	[-1.94]	[-1.95]	[-1.95]	[-1.84]	[-1.99]
IPR_{it-1}	0.308*	0.334*	0.274*	0.627*	0.347*	0.445*	0.451*	0.103*	2.072*	1.403*
	[3.08]	[2.52]	[1.73]	[2.21]	[1.93]	[3.24]	[3.203]	[1.743]	[4.788]	[2.444]
$IPR_{it-1} \times e\&p_{it}$	-0.530*	-0.626*	-0.777*	-1.297*	-0.834*					
	[-8.06]	[-12.0]	[-3.5]	[-5.32]	[-3.44]					
p_{it-1}	3.1E-5*	4.0E-5*	4.1E-5*	4.1E-5*	7E-5*	91E-6*	8.3E-5*	9.1E-5*	4.4E-5*	3.7E-5*
	[4.04]	[4.48]	[3.74]	[3.676]	[6.141]	[1.922]	[1.782]	[2.622]	[1.767]	[2.04]
b_{it-1}	0.016*	0.022*	0.012*	0.099*	0.087*	0.066*	0.075*	.047**	.032**	0.089*
	[2.31]	[2.94]	[2.21]	[1.94]	[1.89]	[2.114]	[2.254]	[1.677]	[1.779]	[7.523]
u_t	.0081*	.0087*	0.013*	0.016*	0.014*	0.014*	0.014*	.0047*	.0025*	.0057*
	[5.397]	[6.776]	[10.57]	[11.11]	[10.29]	[8.87]	[8.67]	[4.29]	[2.30]	[5.764]
t_t	0.0013	0.0015	-0.013*	-0.010*	-0.010*	-.018*	-0.018*	-0.003*	-0.088*	-0.042*
	[0.405]	[0.121]	[-3.21]	[-2.42]	[-2.31]	[-6.24]	[-5.92]	[-2.01]	[-13.5]	[-8.45]
N×T	1822	1822	1822	1701	1701	373	373	373	343	343
MSE	0.1476	0.1012	0.1257	0.1645	0.0995	0.0314	0.0311	0.0175	0.1167	0.055
R^2	0.795	0.804	0.975	0.723	0.971	0.847	0.851	0.993	0.478	0.373
Estimation	WG	WG	WG	WG	WG	WG	WG	WG	WG	WG
Weighted	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
RTS:	Constant		Var.ble	Const.	Var.ble	Constant		Var.ble	Const.	Var.ble
F. F.E.	108.9*	705.3*	731.4*	756.1*	739.2*	303.8*	711.1*	752.3*	756.3*	777.2*
Correction for Heteroscedasticity										
IPR_{it-1}		0.208*	0.202*	0.216*	0.207*		.0351*	0.028*	0.026*	0.025*
White t-ratio		[5.292]	[5.692]	[4.325]	[4.218]		[2.427]	[2.480]	[2.066]	[2.123]
$IPR_{it-1} \times e\&p_{it}$		-0.207*	-0.188*	-0.238*	-0.219*					
White t-ratio		[-5.59]	[-5.35]	[-4.36]	[-3.99]					

Source: Own estimations from the sources in the text.
Note: * Different from zero at 5% or less, ** Different from zero at 10% or less.

Table 8.2 Estimates of Company Efficiency: Third and Fourth Samples

MODEL	(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)
SAMPLE	**E&P, Refining, Marketing (3)**					**E&P, Ref., Mark., Transport (4)**				
D. Variable	**Sales**			**Value Added**		**Sales**			**Value Added**	
y_{it-1}	0.471*	0.463*	0.678*	0.469*	0.691*	0.432*	0.569*	0.687*	0.497*	0.685*
	[12.00]	[12.14]	[18.61]	[11.86]	[18.74]	[10.93]	[17.73]	[17.52]	[11.55]	[17.08]
l_{it}	0.551	0.631	0.081*	0.614	0.067*	0.541	0.506	.0642*	0.611	0.041
			[2.765]		[2.282]			[1.91]		[1.247]
k_{it}	0.449*	0.369*	0.141*	0.386*	0.131*	0.459*	0.494*	0.126*	0.389*	0.118*
	[10.61]	[9.84]	[3.534]	[10.06]	[3.17]	[9.68]	[4.64]	[2.851]	[6.54]	[2.578]
s_{it-2}	-0.19**	-0.285*	-0.193	-0.363*	-0.184	-0.206	-0.561*	-0.146	-0.31**	-0.056
	[-1.74]	[-2.19]	[-1.56]	[-2.21]	[-1.36]	[-1.49]	[-2.31]	[-1.35]	[-1.77]	[-0.87]
IPR_{it-1}	0.586*	0.508*	0.493*	0.532*	0.387*	1.026*	1.069*	.2995*	0.305*	0.355*
	[2.996]	[2.83]	[3.369]	[3.05]	[2.92]	[3.900]	[3.81]	[1.770]	[1.891]	[1.912]
IRM_{it-1}	-0.259	-0.306	-0.073	-0.418*	-0.109	1.297*	1.259*	.731**	0.146	0.594
	[-1.06]	[-1.61]	[-0.46]	[-2.16]	[-0.69]	[2.33]	[3.388]	[1.844]	[1.212]	[1.488]
$ICTR_{it-1}$						-.305*	-0.436*	-0.267*	-0.107	-0.314*
						[-2.21]	[-7.93]	[-2.63]	[-1.05]	[-3.01]
$IRPT_{it-1}$						0.31**	0.664*	0.337*	0.269	0.264
						[1.736]	[2.296]	[1.82]	[1.554]	[1.392]
p_{it-1}	0.006*	0.006*	0.004*	0.004*	0.005*	.004**	0.0019	.005**	0.0006	0.006*
	[1.91]	[2.01]	[2.73]	[2.69]	[2.71]	[1.722]	[1.245]	[1.831]	[0.871]	[2.02]
b_{it-1}	0.088*	0.066*	0.051*	0.0048	0.070*	0.106*	.1045*	0.076*	.0615*	0.096*
	[2.02]	[1.89]	[1.942]	[0.153]	[2.51]	[2.240]	[1.985]	[2.522]	[2.376]	[3.001]
u_t	0.014*	0.014*	0.008*	0.015*	0.008*	0.015*	0.026*	0.076*	0.015*	.0076*
	[8.31]	[7.12]	[5.38]	[7.52]	[5.13]	[7.85]	[11.69]	[4.91]	[6.659]	[4.58]
t_t	-0.025*	-0.028*	-0.013*	-0.027*	-0.011*	-.027*	-0.039*	-0.013*	-0.024*	-0.014*
	[-5.61]	[-7.17]	[-3.78]	[-6.81]	[-3.46]	[-5.60]	[-8.21]	[-3.74]	[-5.49]	[-3.71]
N×T	326	326	326	301	301	285	285	285	260	260
MSE	0.1788	0.1029	0.1124	0.1186	0.1128	0.1833	0.2228	0.1183	1007	0.1162
R^2	0.919	0.975	0.993	0.965	0.993	0.902	0.996	0.994	0.942	0.994
Estimation	WG	WG	WG	WG	WG	WG	WG	WG	WG	WG
Weighted	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
RTS:	Constant		Var.ble	Const.	Var.ble	Constant		Var.ble	Const.	Var.ble
F. F.E.	81.38*	88.83*	130.5*	49.27*	199.5*	51.49*	88.07*	129.4*	41.52*	104.5*
Correction for Heteroscedasticity										
IPR_{it-1}		.0402*	.0177*	.0129*	.028*		.0462*	.0117*	.0571*	.0319*
White t-ratio		[1.87]	[2.543]	[2.416]	[2.653]		[1.976]	[1.932]	[1.820]	[2.271]

Source: Own estimations from the sources in the text.

Note: * Different from zero at 5% or less, ** Different from zero at 10% or less.

Concerning the production function the first issue has to do with the importance of the partial adjustment term. This recognizes the fact that production is essentially dynamic and there is a certain lag in output determination. The partial adjustment coefficient is much larger when sales rather than value added is used as the dependent variable in the first two samples. This is basically the result of leaving materials out of the equation, which are proxied by the lagged value of sales. The exclusion of materials also increases the value of most coefficients in all samples although the signs do not change in any manner.

Worthy of a comment is the fact that the data pushes us in the direction of decreasing returns to scale in all samples (models (3) and (5)). The finding of decreasing returns to scale cannot be taken to be representative of the oil industry but is more a feature of the data and the estimation procedure. In fact it is well known in the estimation of production functions that estimators that exploit the time dimension of the panel (e.g. within-groups, difference estimators) point towards the direction of decreasing returns to scale to production (cf. Mairesse (1990), Griliches and Mairesse (1988)). One of the usual reasons for this occurrence is the existence of error in the measurement of the capital input further accentuated by the introduction of firm effects (Griliches and Hausman (1986), Barrera (1994)). Our measure of capital use does not have a very strong claim to accuracy and the instability in the labour and capital coefficients across estimations, plus the extremely low value of the labour coefficient lend support to this hypothesis. In this case, and usually for the study of productivity differences, it is more appropriate to impose constant returns to scale on the data (Nickell (1993)). The imposition of constant returns to scale produces more plausible estimates of the labour and capital elasticities (α and β) which are also more stable within each sample.

The imposition of constant returns to scale to the data does not have a bearing on the behaviour of the other coefficients with the exception of the share in industry sales. Positive deviations in market share tend to have a detrimental effect on deviations in productivity. This borders on significance in the second sample and in the constant returns to scale estimation in the third and fourth samples but does not hold at all in the first sample. That the share in production does not proxy market power is not surprising in our model but its inadequacy is perhaps more pronounced in the first sample. The reason is that the definition of the "market" is less appropriate when firms are more heterogeneous and are perhaps not in direct competition. When the market definition is narrowed down we observe a result compatible with the assumption of the existence of slack found in other studies.[27]

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[27] See Nickell (1993), and Barrera (1994).

The existence of slack is corroborated by the coefficients of the measure of competition by comparison (p). The coefficient is significant in all cases at, at least, 5% level with the exception of constant returns to scale in the fourth sample. The positive coefficient implies that as the level of profitability of the company falls *vis à vis* all other companies' profitability the firm is forced to improve its efficiency.

The borrowing ratio is also a good performer in most samples. It is significant at, at least, 5% in most estimations, and the sign of the coefficient is robust to sample changes. The sign suggests that indebted companies are forced to improve their productivity, an argument related to the discipline of debt hypothesis. Although not shown in the table, the coefficient differs for companies involved in only exploration and production, and for the rest of the companies in sample (1). In fact, the coefficient turns out to be negative for solely producing companies, and positive for producing and refining companies.[28] This is not incompatible with the definition of exploration as a high risk activity where large amounts of self financing are necessary.

One of the more consistent performers is the index of demand pressures, u, or rate of capacity utilisation. The index shows that when demand is strong productivity improvements are more feasible and a similar phenomenon is known as Verdoorn's law. The significance of the coefficient is very large and exhibits no large variation to sample changes. The comment also extends to the trend, it shows a yearly fall in sales and value added although the coefficient varies with the model and the sample chosen.

Coming now to the issue of importance for us, the role of vertical integration in refining and production is very consistent in all samples. The results show how the level of vertical integration reduces the level of efficiency of the company. However, in the first sample the result only holds if the e&p dummy is interacted with the measure of integration.[29] The interacted dummy is highly significant and shows that greater levels of integration are associated with low levels of productivity. It also shows that firms involved in refining have higher levels of efficiency but efficiency falls with the intensification of integration. In other words, entering into refining is initially efficient but avoiding the market reduces the level of efficiency.

The result concerning the reduction of efficiency following the deepening of integration is also

[28] The resulting coefficients for companies in E&P only (t-ratios for e&p×b in brackets) is equal to -.0026 [-1.31], -.0057 [-1.94], -.0091 [-3.21], -.0122 [-3.64], and -0.013 [-4.19] for models (1) to (5) respectively.

[29] Initial estimations excluding the e&p dummy showed a negative and highly significant coefficient on the *IPR* variable. This suggests that integrated companies have a higher level of efficiency. The results presented in Table 8.1 conclude that this is not the case if the slope of the variable is allowed to differ.

found in the second sample. Contrary to most other variables the coefficient of *IPR* increases when value added is used as the dependent variable. This, perhaps, is because barrels produced are in the numerator of the *IPR* variable and as such may proxy materials use. The introduction of the variable proxying integration between the refining and marketing stage does not affect dramatically the significance of the variable. Table 8.3 reports on elasticities of the integration variables at sample means which may be used to assess the marginal effects of integration.

Table 8.3 Elasticities of Vertical Integration Variables at Sample Means.

MODEL	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**
SAMPLE	**E&P or Refining (1)**					**E&P and Refining**				
IPR_{it-1}	0.0247	0.0263	0.0095	0.0501	0.0120	0.0173	0.0175	0.0170	0.0253	0.0236
IPR_{it-1}×e&p_{it}	-0.007	-0.008	-0.004	-0.001	-0.005					
Correction for Heteroscedasticity										
IPR_{it-1}		0.8132	0.8993	0.7598	0.8132		0.2961	0.4733	0.2301	0.4632
IPR_{it-1}×e&p_{it}		-0.138	-0.142	-0.144	-0.148					
SAMPLE	**E&P, Refining and Marketing**					**E&P, Ref., Mark. and Transport**				
IPR_{it-1}	0.0214	0.0191	0.0071	0.0200	0.0056	0.0376	0.0395	0.0044	0.0113	0.0052
IRM_{it-1}	-0.004	-0.004	-0.001	-0.005	-0.001	0.0144	0.0141	0.0032	0.0015	0.0025
$ICTR_{it-1}$						-0.011	-0.015	-0.004	-0.004	-0.004
$IRPT_{it-1}$						0.0181	0.0389	0.0078	0.016	0.0063
Correction for Heteroscedasticity										
IPR_{it-1}		0.319	0.287	0.109	0.494		0.367	0.621	0.495	0.582

Source: Tables 8.1 and 8.2.

The elasticities differ somewhat if the assumption of constant returns to scale is not made. If constant returns to scale are imposed on the production function, the first sample shows how a 1% rise in integration reduces the level of efficiency by a quarter of 1% (or a tenth of 1% in the variable returns to scale case), while for companies engaged in only production the decision to enter the refining stage would represent a gain of half a percent in their efficiency. More dramatic is perhaps the reduction in efficiency variation where a 1% reduction in integration adds almost 0.9% to firm risk.[30]

The second sample exhibits a lower impact of vertical integration on company efficiency if the dependent variable is sales (models (1) to (3)), but a similar amount if the dependent variable is value added. In contrast to the previous sample, there is no marked difference between the elasticities when relaxing the constant returns to scale constraint. Also in comparison with the previous example, the reduction in business risk is not as great as in sample (1) but still is around

[30] My attention has been drawn to the fact that, given the central limit theorem, it is perhaps trivial to report that the addition of one stage reduces the variance of efficiency. The results reported here claim that is the addition of refining to E&P that has this effect. Similarly, the decision to bypass the market results in reductions in efficiency variation.

0.25 to 0.5.

The production-refining integration variable performs very well in all our estimates, but the same cannot be said about the other integration proxies. In particular, the IRM variable performs very poorly in the third sample where it is significant in only one estimation (model (4)). Not only is it non-significant, but the sign of the coefficient points to a greater level of efficiency of more integrated companies which is more in line with the market power interpretation (internalization of the mark-up) rather than the diseconomies of diversification argument. It is possible that the variable is proxying the effects of integration into petroleum products transport, and in fact the introduction of vertical integration into transportation variables reverses the result. The variable turns positive in the last sample but is only significant in the models using sales as the dependent variable. When significant it is seen that a 1% increase in integration into marketing reduces efficiency by 0.03 to 0.01 per cent .

The measures proxying vertical integration into transportation suffer from the same lack of consistency although their relative performance varies. For example, integration between crude transportation and refining is significant in most models with the exception of model (4) and shows higher efficiency for more integrated companies. This may be because crude oil transport might be considered as just an additional process in the refining business. In contrast to ICTR, the measure of integration into products transport is significant in one less instance and is only significant in the models using sales as a dependent variable. In this stage integration is once more related to the concept of slack coming from coordination and perhaps size.

Although the results concerning uncertainty are quite robust, it must be said that only the measure of vertical integration between the two initial stages proved robust to sample and model modifications, in terms of significance and also sign. Inclusion of the other integration variables did not affect greatly the estimates of the productivity equation, but were not significantly different from zero in the variance regressions. The positive coefficient of *IPR* in the variance regression is consistent with the argument of a reduction in risk by diversification and is related to the results by Levin (1981) and Al-Obaidan and Scully (1993). The importance of our results compared to theirs is that we have modelled risk implicitly in the model of determinants of integration.[31] The reason variability is related to IPR only is either because integration in the first two stages is already accounting for the degree of diversifiable risk, that our measure of risk is proxying, or alternatively because uncertainty may be more pronounced in these two segments.

[31] Broadman (1981) prefers to isolate the effect integration has on the variability of profits by including the beta coefficient (coefficient of determination between the firm's rate of return and the rate of return of a risk-free asset) as an additional explanatory variable.

This is because our measure of risk, unlike the *beta* coefficient, fails to account for the performance of other companies in the same sector.

Thus far the models presented have assumed that the time conditions in the market have been invariant. From Chapter 2 it is recalled that some time variation can be associated with the effects of integration. Chapter 3 also showed that integration has no clearly defined trend, increasing but also falling at times. This is presumably the result of time-specific costs and benefits of integration. In spite of the fact that degrees of freedom, given the length of the panel, become a constraint when incorporating the various shocks suffered by the industry between the sample period of 1974-1993, we conducted a couple of experiments with period breaks in the function (9). We also attempted to follow the results of Levin (1981) and tested whether overseas production accounted for efficiency differences by introducing the firm ratio of US to world production as an additional explanatory variable. Contrary to what Levin and McLean and Haigh (1954) found the regional composition of production does not make a difference to our estimates.

Experiments with breaks in the function were conducted for different periods. The most consistent results are found in a model where the sample period is divided between 1974-1985 and 1986 and after. The break year represents the large fall in the oil price after the decision by Saudi Arabia to increase its production following years of reducing crude production to keep prices high. It is also believed that the performance of markets would have improved by then and perhaps the cost of transactions would have fallen. For example, in September 1985 the first crude oil warrants were launched by the financial institution Phibro Salomon Inc. and were followed by options traded in the New York Mercantile Exchange. Furthermore, the degree of intermediation of NYMEX had almost doubled between 1985 and 1986 to a volume equivalent to almost the production of OPEC (Chassard and Halliwell (1986)). It is presumed that the risk of transacting in crude oil might have been reduced and perhaps with the ensuing relaxation of the market-related constraint. As a result the aforementioned benefits from vertical integration could have been affected.[32]

Breaks in the function were only analysed for the effect of *IPR* on both the level and the variability of efficiency. The time dummy (interacted with IPR slope) proved significant in all models for samples (2)-(4) in both the weighted productivity and the variance regressions. In all cases also, the coefficient of the interacted dummy variable was negative and different from zero. This implies

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[32] The year 1986 is also the first year since 1973 in which profitability of the major American energy producers in Refining/Marketing exceeds profitability in Production (see US Energy Information Administration *Performance Profiles of Major Energy Producers* Dec 1994).

a reduction in the inefficiency associated with integration, but also a reduction in the effectiveness of integration to reduce risk after 1985.

To illustrate the magnitude of losses in efficiency and gains in risk reduction according to the degree of vertical integration in production and refining, we have calculated the difference between the predicted values of both efficiency and risk in 1974-1985 and 1986-1993. The predicted values are calculated at the sample means of all the left hand side variables in equation (4), while allowing *IPR* to vary. The result of subtracting the predicted values for the second period from those in the first period is presented in Figures 8.1 and 8.2. The model chosen is model (9) above, the model with value added as a dependent variable and constant returns to scale for samples (2) to (4) where the break in the function is significant..

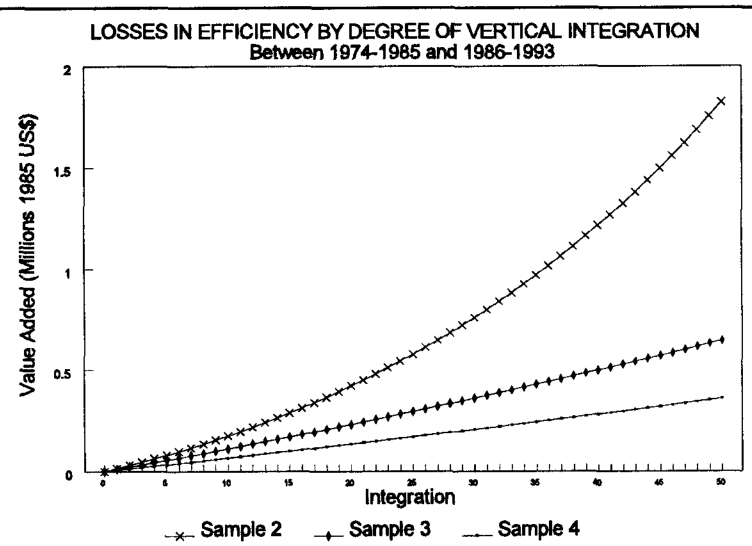

Figure 8.1

Figure 8.1 shows that efficiency after 1986 falls at all levels of integration, but it is much larger for the sample of firms involved in both refining and producing oil (sample 2). The losses in efficiency vary from US$400,000 (sample 4) to US$ 1.8 million (sample 2) for a non-integrated company (at 1985 prices). Figure 8.2 shows that the effectiveness of integration in reducing efficiency variation is diminished after 1986 for all levels of integration. The losses in risk reduction are also large and range for a non-integrated company between 2% and 3.2% and for the median company between 1% and 1.5%.

The reduction in risk gains is compatible with an improvement in the ability of markets to convey more information and also concordant with the reduction in the risk of not finding partners in a transaction coming from a growth in the activity of futures markets. The losses in efficiency come perhaps from the collapse in the price of oil and the discipline exerted by the mergers wave in the second half of the 1980s.

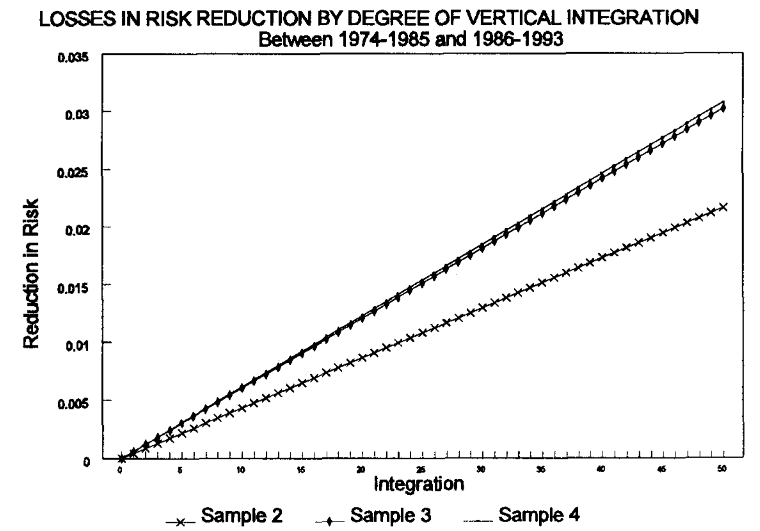

Figure 8.2

9. CONCLUSIONS

This study has endeavoured to complement the empirical economic literature on the effects of vertical integration. An empirical, rather than a theoretical, approach has been used in this study to account for the observed pattern of different integration strategies followed by companies in specific segments of the oil industry. This pattern, found not exclusively in the oil industry, suggested the use of a cost-benefit approach to appraise the decision to integrate as it enabled us to quantify the advantages and disadvantages of vertical integration. In accordance with the definition of vertical integration as the decision to use internal rather than market transactions, costs and benefits are calculated in terms of transaction costs and diseconomies of size and diversification. The results suggest that the decision to integrate is a firm-specific decision.

The innovation of the study comes from dealing with costs and benefits in an unified manner and the coverage of the four main distinguishable stages of the industry, which are: exploration and production, refining, crude and oil products transportation, and wholesale marketing. The unified empirical methodology followed is based on the analysis of the effects of integration on the level and variability of the economic efficiency of companies using a heteroscedasticity-correction technique.

While the emphasis of the study is on the effects of vertical integration, some interesting results concerning the determinants of company efficiency have been found. In the first instance the positive effect that competition has on company performance is corroborated by the use of measures of market power and 'competition by comparison'. Market power seems to reduce company efficiency probably because of the slack and complacency associated with monopoly. 'Competition by comparison' with other companies in the industry lead firms to improve their performance when they deviate from the industry norm. Secondly, the upswing in the business cycle associated with an increase in utilised refining capacity allows improvements in company efficiency.

Although the study includes companies in any of the four stages of the industry, only companies engaged in solely exploration and production exhibit differences from the remaining companies in the way certain variables affect efficiency. Firstly, company indebtedness reduces the efficiency of companies engaged in E&P only, while the discipline of debt forces other companies to increase their efficiency as suggested by arguments that equate efficiency and effort. Secondly, non-integrated companies engaged in E&P only, have lower efficiency levels than companies engaged in refining only; or refining and E&P (and thus more integrated). Thirdly, not only are these companies less efficient but also show greater variation in efficiency. These relationships between vertical integration and greater level and variation in economic efficiency fail to hold for other companies and can be regarded as a peculiar feature of the exploration and production segment.

With respect to integration the most consistent results in terms of sample and econometric specification are found at the E&P and refining junction. On the one hand, our results point to a detrimental effect of integration on economic efficiency perhaps as a result of the diseconomies of size and diversification. On the other hand a greater degree of integration in these two stages is associated with a reduction in the variability of economic efficiency. The relationship between variation and integration is a feature of companies engaged in these two stages.

The role of integration in other stages is less clear. First, as mentioned in the previous paragraph, it is not related to efficiency variation, perhaps because uncertainty is greater in the E&P and refining segments. Secondly, we found that the refining-marketing measure produces consistent results only when integration into oil products transportation is accounted for as it shows then the same negative effect on the level of efficiency. The only case in which a higher degree of integration is positively related to company efficiency is crude oil transportation. We conjecture that the reason for this anomaly is that this segment seems to be an integral part of the refining activity and the benefits to integrating these two activities are large.

Finally, although the effects integration on efficiency have a strong structural component, we have also found that their benefits in variability reduction have fallen recently. In other words the cost of relying on market transactions are now smaller as are also the costs of delegation and diversification. The reduction in the costs of using the market could account for the recent historic trend towards lower levels of vertical integration in the oil industry.

Two main aspects of the vertical integration issue have been left untouched in this study and are regarded as areas for future research. First, we have left out the analysis of the retailing stage. Second, contracts rather than markets could be the focus of analysis. The use of markets in this study dictated the exclusion of the retailing stage from our analysis as the issue of contracts arises more prominently in that segment rather than the stages covered in this study.

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APPENDIX I: METHODOLOGY FOR THE CALCULATION OF FIRM SHARE IN INDUSTRY SALES

Given that the number of companies in the database differs from year to year, and given also that not all firms are likely to be included in every period, a methodology to calculate the share of each company in industry sales is calculated. The importance of the measure comes from imperfect competition and market power considerations.

1-. A measure of total sales must be constructed.

a-. Calculate the average industry sale in year t as:

$$ASAL_t = \frac{1}{N_t}\sum_{i=1}^{N} Sales_{it}$$

b-. A measure of total sales is constructed by multiplying average sales in year t by the annual average of companies. The average number of companies is :

$$\bar{N} = \frac{1}{T}\sum_{t=1}^{T} N_t$$

which multiplies ASAL to get:

$$TSAL_t = ASAL_t \times \bar{N},$$

a measure of total sales in year t.

2-. The share of company i in year t sales is equal to:

$$s_{it} = \frac{Sales_{it}}{TSAL_t}.$$

The measure has the feature that the average share in a given year is equal to the inverse of the average number of firms, which is what would be expected if all companies were equally efficient.

APPENDIX II: SAMPLE OF COMPANIES

COMPANY	Period	VI	COMPANY	Period	VI
ADAMS RES. & EN.	1975 - 93	S	DENISON MNS.,US.	1974 - 80	N
ALBION INTL.RES.	1984 - 88	N	DEVON ENERGY	1988 - 93	S
ALEXANDER ENERGY	1981 - 93	N	DOMINION RES.	1974 - 93	N
ALLEGHENY & WSTN.EN.	1985 - 93	S	ENERGEN	1974 - 93	N
ALTA ENERGY	1990 - 93	N	ENERGETICS	1986 - 91	N
ALTEX INDS.	1985 - 92	N	ENRON CORP	1974 - 93	S
AMACAN RESOURCES	1975 - 93	N	ENSERCH	1974 - 93	N
AMAX	1974 - 92	N	EQUITABLE RES.	1974 - 93	S
AMER.EXPLORATION	1983 - 93	N	EQUITY OIL	1974 - 93	N
AMER.OIL & GAS	1982 - 93	N	ESSEX	1981 - 93	N
AMER.PACIFIC	1974 - 93	S	EVERGREEN RES.	1989 - 93	N
AMER.PLASTICS CHEMS.	1988 - 91	N	EXPLORATION CO.	1980 - 92	N
AMERADA HESS	1974 - 93	F	EXXON	1974 - 93	F
AMOCO	1974 - 93	F	FALCON OIL & GAS	1980 - 93	N
ANADARKO PTL.	1985 - 93	N	AM. PETROFINA	1974 - 93	F
APACHE	1974 - 93	S	1ST.MISSISSIPPI	1974 - 93	N
APACHE PTL.	1981 - 87	N	FOREST OIL	1974 - 93	S
ARCH.PTL.	1983 - 93	N	FORTUNE PETE	1987 - 93	N
ARCO CHEM.	1987 - 93	N	FREEPORT MCMORAN ENE	1986 - 89	N
ARTRA GROUP	1974 - 93	N	FREEPORT-MCMOR.OIL &	1984 - 93	N
ASHLAND OIL	1974 - 93	F	GARNET RESOURCES	1987 - 93	N
ASPEN EXP.	1981 - 92	N	GATX	1974 - 93	S
ATLANTIC RICH.	1974 - 93	F	GEODYNE RES.	1980 - 92	N
BEARD CO.	1974 - 80	N	GEORESOURCES	1975 - 93	N
BELDEN & BLAKE	1984 - 90	S	GETTY PTL.	1975 - 83	F
BOW VALLEY ENERGY	1975 - 80	N	GLOBAL MARINE	1974 - 93	N
BRASCAN	1978 - 93	N	GLOBAL NTRL.RES.	1980 - 93	N
BROCK EXP.	1975 - 93	N	GRACE ENERGY	1988 - 91	N
BURLINGTON RES.	1987 - 93	N	GT.EASTERN EN.	1980 - 93	N
BUTTES GAS & OIL	1974 - 84	S	GULF CANADA RES.	1987 - 93	N
CABOT	1974 - 93	P	GULF CORP.	1974 - 84	F
CALUMET INDS.	1974 - 80	N	GULFMARK INTL.	1974 - 93	N
CAN.STHN.PTL.	1975 - 93	N	HADSON	1975 - 93	S
CASTLE ENERGY	1985 - 93	N	HALLIBURTON	1974 - 80	N
CDN.OCCIDENT.PTL.U$	1974 - 93	F	HALLWOOD ENERGY	1980 - 80	N
CHAPARRAL RES.	1974 - 80	S	HAMILTON OIL	1974 - 80	N
CHEVRON	1974 - 93	F	HARKEN ENERGY	1979 - 93	N
CMS ENERGY	1974 - 93	N	HELMERICH PAYNE	1974 - 80	N
CMWL.OIL	1974 - 89	S	HOLLY	1974 - 93	N
COASTAL	1974 - 93	S	HOWELL	1974 - 93	F
COBB RES.	1975 - 92	N	HUBCO	1982 - 93	N
CODA ENERGY	1983 - 93	N	IMPERIAL OIL	1974 - 93	F
COLONIAL GAS	1977 - 93	S	K N ENERGY	1974 - 93	S
COLUMBUS ENERGY	1987 - 93	N	KANEB SERVICES	1974 - 93	S
CONVEST ENERGY	1985 - 93	N	KCS ENERGY	1988 - 93	S
CROWN CTL.PTL.A	1974 - 93	S	KELLEY OIL	1985 - 93	S
CRYSTAL OIL	1974 - 80	S	KELLY OIL & GAS	1986 - 93	N
DALECO RES.	1984 - 93	N	KERR-MCGEE	1974 - 93	F
DAMSON OIL	1974 - 80	N	KIMCO ENERGY	1981 - 90	N
DANAHER	1974 - 93	N	KIRBY EXP.	1976 - 93	S
DBLE.EAGLE PTL.& MNG	1974 - 93	N	LL&E	1984 - 93	S
DEKALB ENERGY B	1974 - 80	N	LNA.LAND & EXPLORATI	1974 - 93	N

Note: VI: F=Fully-Integrated; S=Semi-Integrated; N=Non-Integrated.

COMPANY	Period	VI	COMPANY	Period	VI
MAGELLAN PTL.	1976 - 93	N	SAN JUAN BASIN REAL.	1981 - 93	N
MAGIC CIRCLE EN.	1980 - 90	N	SANTA FE EN.PTNS.LP.	1986 - 92	S
MAPCO	1974 - 93	F	SCOPE INDS.	1974 - 93	N
MAXUS ENERGY	1974 - 93	N	SEAGULL ENERGY	1981 - 93	S
MAYNARD OIL	1975 - 93	N	SNYDER OIL	1983 - 89	N
MCFARLAND ENERGY	1976 - 84	S	SONAT	1974 - 93	S
MDU RES.	1974 - 84	N	SOUTHWEST ENERGY	1974 - 93	N
MOBIL	1974 - 93	F	STD.OIL & EXP.	1988 - 90	N
MONTANA POWER	1974 - 93	N	STHN.MINERAL	1975 - 93	N
MORGAN PRDS.	1985 - 93	N	STHN.UNION	1974 - 88	N
MSR EXPLORATION	1982 - 93	N	STOLT TKRS.& TERMINA	1988 - 92	N
MURPHY OIL	1974 - 93	F	STONE & WEBSTER	1974 - 93	N
NAHAMA & WEAGANT EN.	1980 - 93	N	SUN	1974 - 93	F
NEWPARK RES.	1974 - 91	N	SUNLITE	1974 - 93	N
NOBLE AFFILIATES	1974 - 80	N	SUNSHINE MINING	1974 - 93	N
NOVA CORP.ALTA	1978 - 93	N	SWIFT ENERGY	1980 - 84	N
NUMAC ENERGY	1974 - 93	N	TENNECO	1974 - 80	F
OCCIDENTAL PTL.	1974 - 93	S	TESORO PETROLEUM	1974 - 80	F
OCEANIC EXP.	1974 - 93	N	TEXACO	1974 - 80	F
OIL CITY PETROL	1979 - 93	N	TGX CORP	1982 - 93	S
ONEOK	1974 - 93	N	THOR ENERGY RES.	1975 - 93	N
ORYX EN.	1987 - 93	N	TIDEWATER	1975 - 93	N
OXFORD ENERGY	1985 - 91	N	TOREADOR ROYALTY	1974 - 84	N
PACIFIC ENTS.	1974 - 93	N	TOSCO	1974 - 93	S
PARK.PARSLEY DEV.	1987 - 89	N	TOTAL U.S.	1974 - 93	F
PARKER DRILLING	1974 - 93	N	TPEX EXP.	1980 - 84	S
PARTNERS OIL CO.A	1981 - 93	N	TRANSCO ENERGY	1974 - 93	S
PATRICK PTL.	1975 - 93	N	TRANSCO EXP.PTSHP.UT	1984 - 91	N
PENN PACIFIC	1979 - 91	N	TREDEGAR INDS.	1988 - 93	N
PENN VA.	1974 - 93	N	TRITON ENERGY	1975 - 93	N
PENNZOIL	1974 - 93	F	TUCKER DRILLING	1975 - 93	N
PERMIAN BASIN	1981 - 93	S	TYREX OIL CO.	1981 - 93	N
PETROL INDS.	1974 - 93	N	U.S.OIL CO.	1980 - 88	S
PETROMINERALS	1979 - 80	S	UNIMAR	1985 - 93	S
PHILLIPS PTL.	1974 - 80	F	UNION PACIFIC	1974 - 93	F
PLAINS PTL.	1985 - 93	N	UNION TEXAS PTL.	1985 - 93	N
PLAINS RES.	1980 - 93	N	UNIT CORP.	1979 - 93	N
POGO PRODUCING	1974 - 93	S	US.ENERGY	1974 - 93	N
PRDN.OPERATORS	1975 - 93	N	VALERO	1979 - 93	S
PRESIDIO OIL	1977 - 93	S	WAINOCO OIL	1974 - 93	N
PRIMA ENERGY	1981 - 93	N	WASH.EN.	1974 - 80	N
PTL.& RES.CORP.	1982 - 85	N	WEATHERFORD INTL.	1974 - 93	N
PTL.DEV.	1974 - 93	N	WESTERN EN.RES.	1985 - 93	N
PYRAMID OIL	1974 - 93	N	WICOR	1975 - 80	N
QUAKER STATE	1974 - 93	F	WILLIAMS COS.	1974 - 80	S
QUESTAR	1974 - 93	N	WILSHIRE OIL TX.	1974 - 93	N
RANGER OIL (U$)	1974 - 93	N	WISER OIL	1974 - 80	N
READING & BATES	1974 - 91	N	WITCO	1974 - 93	N
RESERVE INDS.	1974 - 84	N	WOLVERINE EXP.	1974 - 93	N
RESOURCE AM.	1982 - 84	S	WOODBINE PTL.	1981 - 84	N
ROWAN COS.	1974 - 84	N	XCL LTD.COM.	1986 - 93	N
SABINE ROYALTY TST.	1984 - 84	N	ZAPATA CORP.NEW	1974 - 93	N
SAGE ENERGY	1978 - 93	N			

Note: VI: F=Fully-Integrated; S=Semi-Integrated; N=Non-Integrated.

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