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ECONOMIES OF SCOPE AND THE SCOPE OF THE ENTERPRISE

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This paper examines elements of an efficiency-based theory of the multiproduct firm. The theoretical framework developed by Williamson to explain vertical integration is extended to explain diversification. The proposition is advanced that a cost function displaying economies of scope has no direct implications for the scope of the business enterprise. However, if economies of scope are based upon the common and recurrent use of proprietary knowhow or the common and recurrent use of a specialized and indivisible physical asset, then multiproduct enterprise (diversification) is an efficient way of organizing economic activity. These propositions are first developed in a general context and then examined in the context of diversification in the U.S. Petroleum industry.

1. Introduction

Explaining the scope of activities pursued by the modern business enterprise is clearly central to our understanding of the organization of industry. Yet, as Ronald Coase points out, the received theory of industrial organization is unable to explain why General Motors is not a dominant factor in the coal business, or why A & P does not manufacture airplanes [Coase (1972, p. 67)]. Nor does the received theory explain why aircraft manufacturers are now producing missiles and space vehicles, why Union Oil is producing energy from geothermal sources, or why Exxon is looking for uranium. One reason for this neglect is suggested by Nelson's observation that microeconomic analysis views the enterprise as little more than a black box, and the distribution of economic activity between markets and firms is taken as datum [Nelson (1972, p. 37)]. While sometimes it suffices to take institutions as pre-existing entities and model economic phenomena in familiar demand and cost curve terms, there are other circumstances where it is instructive to begin with more elemental units of analysis. Firms, after all, do not come in predetermined shapes, and neither do markets. Rather, both evolve in active juxtaposition with one another.

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the object being to reach a complementary configuration that economizes on (production and) transactions costs' [Williamson (1978)].

The purpose of this paper is to explore some comparative institutional considerations which surround the scope of the business activities engaged in by the modern business enterprise. Specifically, the paper explores an efficiency rationale of corporate diversification.[1] It turns out that the theoretical framework developed by Williamson to explain vertical integration [Williamson (1975, ch. 5)] can be extended readily to explore multiproduct diversification. This is because the principal differences between vertical integration and diversification relate simply to the types of transactions being internalized. Whereas vertical integration involves internalizing the supply of tangible inputs (such as components and raw materials) to a single production process, the integration of interest here involves internalization of the supply of knowhow and other inputs common to two or more production processes. It turns out that diversification can represent a mechanism for capturing integration economies associated with the simultaneous supply of inputs common to a number of production processes geared to distinct final product markets.

2. Economies of scope and diversification

Efforts have recently been made to formulate an efficiency-based theory of the multiproduct firm. These endeavors rest upon specifying cost functions which exhibit economies of scope. Economies of scope exist when for all outputs y_1 and y_2, the cost of joint production is less than the cost of producing each output separately[2] [Panzar and Willig (1975)]. That is, it is the condition, for all y_1 and y_2,

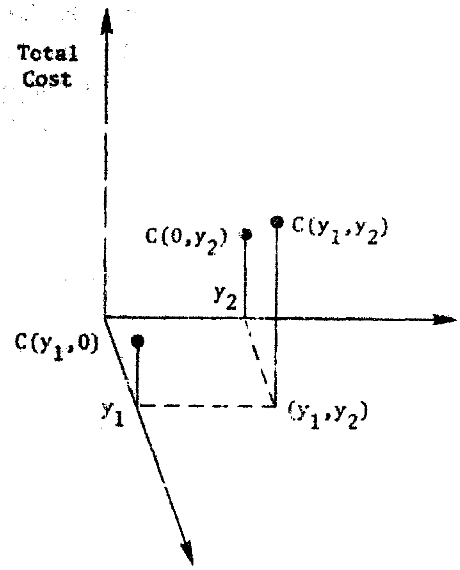
$$c(y_1, y_2) < c(y_1, 0) + c(0, y_2).$$

This is illustrated in fig. 1. According to Panzar and Willig (1975, p. 3), 'it is clear that the presence of economies of scope will give rise to multiproduct firms', and that 'with economies of scope, joint production of two goods by one enterprise is less costly than the combined costs of production of two specialty firms' [Willig (1979, p. 346)].

[1] Following Gort, (1960, p. 9) diversification is defined as 'an increase in the heterogeneity of output from the point of view of the number of markets served by that output'.

[2] More formally, consider a set of products indexed by the numbers in the set $N = (1, 2, \ldots, n)$, with the technology for producing the goods in N being represented by the cost function, $c(x_1, \ldots, x_n)$, which gives the minimal cost of the joint production of the quantities $x_1, \ldots, x_n$ of good $1, \ldots, n$ respectively. There are economies of scope in the production of the set of commodities N if the cost of jointly producing these goods is less than the sum of stand-alone production costs. For example, with $N = (1, 2)$, economies of scope mean that $c(x_1, x_2) < c(x_1, 0) + c(0, x_2)$ for $x > 0$.

The analysis to be engaged here indicates that the Panzar and Willig conclusions are too strong. Economies of scope provide neither a necessary nor a sufficient condition for cost savings to be achieved by merging specialized firms. Even if the technology displays scope economies the joint production of two goods by two firms need not be more costly than production of the two goods by one enterprise. This can be readily established by counterexample.[3] Conclusions about the appropriate



$C(y_1,y_2) < C(y_1,0) + C(0,y_2)$ For All Outputs (y_1,y_2)

Fig. 1. Illustration of economies of scope.

boundaries of the firm cannot be drawn simply by examining the nature of the underlying cost function.[4] Just as technological interdependency between successive stages of a production process do not explain vertical integration [Williamson (1975, ch. 5)] nor do scope economies explain the multiproduct firm. At least, that is the proposition advanced here.

[3]Consider mixed farming. Orchardists must have space between fruit trees in order to facilitate adequate growth of the trees and the movement of farm machinery between the trees. This land can, however, be planted in grass, and sheep may graze to advantage in the intervening pasture. Economies of scope are clearly realized (land is the common input) but the organizational implications are not as sharp as Panzar and Willig's paradigm would suggest. Rather than producing both fruit and sheep, the orchardist can lease the pasture to a sheep farmer. The scope economies in sheep farming and fruit production are realized, but the single product focus of the sheep farmer and the orchardist are preserved. Clearly market contracts can be used to undo the organization implications which Panzar and Willig impute to the cost function.

[4]The cost function summarizes all economically relevant information about the production technology of the firm. But, as commonly interpreted, it does not summarize the firm's organizational technology. To assert otherwise would involve assuming rather than deducing the conditions for efficient multiproduct organization.

A sensitive treatment of the organizational issues involved when the cost function displays economies of scope would indicate that the origin of the scope economies must first be identified. As a general matter, 'economies of scope arise from inputs that are shared, or utilized jointly without complete congestion. The shared factor may be imperfectly divisible, so that the manufacture of a subset of the goods leaves excess capacity in some stage of production, or some human or physical capital may be a public input which, when purchased for use in one production process, is then freely available to another' [Willig (1979, p. 346)]. I submit that the facility with which the common input or its services can be traded across markets will determine whether economies of scope will require the enterprise to be multiproduct in its scope. Where such trading is difficult, and intrafirm governance is superior, then the organizational implications suggested by Panzar and Willig will go through. Only two classes of common inputs can be readily identified where the Panzar and Willig presumption of market failure appears to hold. The common inputs in question are knowhow and specialized and indivisible physical assets. Yet even here, market processes are often sustained. The remainder of this paper seeks to identify the circumstances under which markets for these inputs may break down and where intrafirm transfer is called for. A more tightly circumscribed theory of multiproduct enterprise is suggested. Some illustrations are presented.

3. Knowhow

A principal feature of the modern business enterprise is that it is an organizational entity possessing knowhow. To the extent that knowhow has generic attributes, it represents a shared input which can find a variety of end product applications. Knowhow may also display some of the characteristics of a public good in that it can sometimes be used in many different non-competing applications without its value in any one application being substantially impaired. Furthermore, the marginal cost of employing knowhow in a different endeavor is likely to be much less than its average cost of production and dissemination (transfer). Accordingly, although knowhow is not a pure public good,[5] the transfer of proprietary information to alternative activities is likely to generate scope economies if organizational modes can be discovered to conduct the transfer at low cost. In this regard, the relative efficiency properties of markets and internal organization need to be assessed. If reliance on market processes is surrounded by special difficulties — and hence costs — internal organization, and in particular multiproduct enterprise, may be preferred.

[5] This is because the value of information often declines with its dissemination and it cannot be transferred at zero marginal cost.

An examination of the properties of information markets readily leads to the identification of several difficulties. They can be summarized in terms of (1) recognition, (2) disclosure and (3) team organization. Thus consider a firm which has accumulated knowhow which can potentially find application in fields of industrial activity beyond its existing markets. If there are other firms in the economy which can apply this knowhow with profit, then according to received microtheory, trading will ensue until Pareto Optimality conditions are satisfied. Or, as Calabresi has put it, 'if one assumes rationality, no transactions costs, and no legal impediments to bargaining, all misallocations of resources would be fully cured in the market by bargains' [Calabresi (1968)]. However, one cannot in general expect this happy result in the market for proprietary knowhow. Not only are there high costs associated with obtaining the requisite information but there are also organizational and strategic impediments associated with using the market to effectuate transfer.

Consider, to begin with, the information requirements associated with using markets. In order to carry out a market transaction it is necessary to discover who it is that one wishes to deal with, to inform people that one wishes to deal and on what terms, to conduct negotiations leading up to the bargain, to draw up the contract, to undertake the inspection needed to make sure that the terms of the contract are being observed, and so on [Coase (1960, p. 15)]. Furthermore, the opportunity for trading must be identified. As Kirzner (1973, pp. 215–216) has explained:

> '...for an exchange transaction to be completed it is not sufficient merely that the conditions for exchange which prospectively will be mutually beneficial be present; it is necessary also that each participant be aware of his opportunity to gain through exchange.... It is usually assumed ... that where scope for (mutually beneficial) exchange is present, exchange will in fact occur.... In fact of course exchange may fail to occur because knowledge is imperfect, in spite of conditions for mutually profitable exchange'.

The transactional difficulties identified by Kirzner are especially compelling when the commodity in question is proprietary information, be it of a technological or managerial kind. This is because the protection of the ownership of technological knowhow often requires suppressing information on exchange possibilities. By its very nature, industrial R & D requires disguising and concealing the activities and outcomes of the R & D establishment. As Marquis and Allen (1966, p. 1055) point out, industrial laboratories, with their strong mission orientation, must

> '...cut themselves off from interaction beyond the organizational perimeter. This is to a large degree intentional. The competitive environment in which they operate necessitates control over the outflow

of messages. The industrial technologist or scientist is thereby essentially cut off from free interaction with his colleagues outside of the organization'.

Except as production or marketing specialists within the firm perceive the transfer opportunity, transfer may fail by reason of non-recognition — which of course, is a manifestation of bounded rationality.

Even where the possessor of the technology recognizes the opportunity, market exchange may break down because of the problems of disclosing value to buyers in a way that is both convincing and does not destroy the basis for exchange. A very severe information impactedness problem exists, on which account the less informed party (in this instance the buyer) must be wary of opportunistic representations by the seller. If, moreover, there is insufficient disclosure, including veracity checks thereon, to assure the buyer that the information possesses great value, the 'fundamental paradox' of information arises: 'its value for the purchaser is not known until he has the information, but then he has in effect acquired it without cost' [Arrow (1971, p. 152)].

Suppose that recognition is no problem, that buyers concede value, and are prepared to pay for information in the seller's possession. Occasionally that may suffice. The formula for a chemical compound or the blue prints for a special device may be all that is needed to effect the transfer. However, more is frequently needed. Knowhow has a strong learning-by-doing character, and it may be essential that human capital in an effective team configuration accompany the transfer.[6] Sometimes this can be effected through a one-time contract (a knowhow agreement) to provide a 'consulting team' to assist start-up. Although such contracts will be highly incomplete, and the failure to reach a comprehensive agreement may give rise to dissatisfaction during execution, this may be an unavoidable, which is to say irremediable, result. Plainly, integration (diversification) is an extreme response to the needs of a one-time exchange. In the absence of a superior organizational alternative, reliance on market mechanisms is thus likely to prevail.

Where a succession of proprietary exchanges seems desirable, reliance on repeated contracting is less clearly warranted. Unfettered two-way communication is needed not only to promote the recognition and disclosure of opportunities for information transfer but also to facilitate the execution of the actual transfer itself. The parties in these circumstances are joined in a small numbers trading relation and, as discussed by Williamson, such contracting may be shot through with hazards for both parties [Williamson

[6]'Over the years an individual may learn a piece of the company puzzle exceptionally well and he may even understand how the piece fits into the entire puzzle. But he may not know enough about the other pieces to reproduce the entire puzzle' [Lieberstein (1979)].

(1975, 1979)]. The seller is exposed to hazards such as the possibility that the buyer will employ the knowhow in subtle ways not covered by the contract, or the buyer might 'leap frog' the licensor's technology and become an unexpected competitive threat in third markets. The buyer is exposed to hazards such as the seller asserting that the technology has superior performance or cost reducing characteristics than is actually the case; or the seller might render promised transfer assistance in a perfunctory fashion. While bonding or the execution of performance guarantees can minimize these hazards, they need not be eliminated since costly haggling might ensue when measurement of the performance characteristics of the technology is open to some ambiguity. Furthermore, when a lateral transfer is contemplated and the technology has not therefore been previously commercialized by either party in the new application, the execution of performance guarantees is likely to be especially hazardous to the seller because of the uncertainties involved [Teece (1977)]. In addition, if a new application of a generic technology is contemplated. recurrent exchange and continuous contact between buyer and seller will be needed. These requirements will be extremely difficult to specify ex ante. Hence, when the continuous exchange of proprietary knowhow between the transferor and transferee is needed, and where the end use application of the knowledge is idiosyncratic in the sense that it has not been accomplished previously by the transferor, it appears that something more than a classical market contracting structure is required. As Williamson (1979, p. 250) notes 'The nonstandardized nature of (these) transactions makes primary reliance on market governance hazardous, while their recurrent nature permits the cost of the specialized governance structure to be recovered'. What Williamson refers to as 'relational contracting' is the solution: this can take the form of bilateral governance, where the autonomy of the parties is maintained; or unified structures, where the transaction is removed from the market and organized within the firm subject to an authority relation [Williamson (1979, p. 250)]. Bilateral governance involves the use of what Williamson has labelled 'obligational contracting' (Wachter and Williamson (1978), Williamson (1979)]. Exchange is conducted between independent firms under obligational arrangements, where both parties realize the paramount importance of maintaining an amicable relationship as overriding any possible short-run gains either might be able to achieve. But as transactions become progressively more idiosyncratic, obligational contracting may also fail, and internal organization (intrafirm transfer) is the more efficient organizational mode. The intrafirm transfer of knowhow avoids the need for repeated negotiations and ameliorates the hazards of opportunism. Better disclosure, easier agreement, better governance, and therefore more effective execution of knowhow transfer are likely to result. Here lies an incentive for enterprise diversification.

The above arguments are quite general and extend to the transfer of many different kinds of proprietary knowhow. Besides technological knowhow, the transfer of managerial (including organizational) knowhow, and goodwill (including brand loyalty) represent types of assets for which market transfer mechanisms may falter, and for which the relative efficiency of intrafirm as against interfirm trading is indicated.

Figs. 2 and 3 attempt to summarize the essential dimensions of the above arguments. The matrix in fig. 2 identifies some illustrative knowhow transactions for which governance structures need to be designed. The match of governance structures with transactions which economizes on transactions costs and facilitates efficient knowhow transfer is displayed in fig. 2. Suggested by Williamson (1979, p. 247, 253) these figures are a gross simplification of the real world, which cannot of course be so neatly categorized. Still, the figures serve to identify key considerations likely to determine whether multiproduct organizations will be needed to facilitate the efficient utilization of knowhow which is to become an input into a number of different production processes.

		CHARACTERISTICS OF KNOW-HOW			
		NON PROPRIETARY →		PROPRIETARY	
		nonspecialized application	specialized application	nonspecialized application	specialized application
FREQUENCY OF TRANSFER	occasional	transfer of standard engineering service for particular product or process	transfer of custom engineering services for particular product or process	transfer of "spin-off" technology with nonspecialized application	transfer of "spin-off" technology with specialized application
	↓ recurrent	transfer of know-how for well known process (e.g., thermal cracking of petroleum)	application of well known process to new use (e.g., packaging technology modified for new product)	transfer of process know-how in standard formulation to firms in other markets (e.g., petroleum platforming technology)	transfer of know-how for specialized application in another industry (e.g., aircraft technology applied to aerospace development)

Fig. 2. Illustrative knowhow transactions.

4. Indivisibilities: Market failure considerations

An indivisible asset, or any asset which yields scale economies, can similarly provide the foundation for scope economies if it serves as an input into two or more production processes. At least two types of indivisibilities can be distinguished [Williamson (1975, p. 42)] The first type involves the utilization of a physical asset. Larger scale units, if they are utilized at design capacity, permit lower average costs to be realized. Whenever this kind of indivisibility exists, and whenever the indivisible asset can serve as a common input into two or more production processes, joint production will produce economies of scope. Thus if a machine used to stamp automobile bodies displays economies of scale, and these economies are not exhausted over the range of the market, and if the stamping facility can also be used to stamp truck bodies, then economies of scope will exist in the stamping of both automobiles and light trucks. The second type of indivisibility involves the indivisibilities associated with information, an indivisibility that was explicitly discussed above with respect to knowhow. Radner (1970, p. 457) observes that 'the acquisition of information often involves a 'set up cost' i.e., the

		CHARACTERISTICS OF KNOW-HOW			
		NON PROPRIETARY → PROPRIETARY			
		nonspecialized application	specialized application	nonspecialized application	specialized application
FREQUENCY OF CONTEMPLATED TRANSACTIONS	occasional	markets	markets	markets	markets
	↓	markets	markets	obligational contracting	obligational contracting/ intrafirm organization
	recurrent			obligational contracting/ intrafirm organization	intrafirm organization

Fig. 3. Some elements of organizational design.

resources needed to obtain the information may be independent of the production process in which the information is used'. The set up cost to which Radner refers might be the cost of R & D, or it may simply be the cost of collecting information on a phenomenon of interest. Since the discussion in section 3 above has focussed on the organizational implications of scope economies based on the sharing of information (knowhow), the discussion here will focus on the organizational implications of scope economies based on the sharing of a specialized physical asset.

Clearly, the realization of scope economies based on the sharing of a specialized asset does not imply, as a technological imperative, that the relevant products must be produced within a multi-product enterprise. In the absence of transactional difficulties, there is nothing to prevent one individual or firm from procuring the physical asset in the requisite size to realize the economies in question and contracting to supply the services of this asset to other individuals or firms. All parties could be independent, yet scope economies could be fully realized. In the above example, the automobile manufacturer could own the stamping facility and the truck manufacturer could contract with the automobile manufacturer to have the requisite number of truck bodies stamped in the automobile manufacturer's facility. Alternatively, a third firm could own the stamping facility and contract its services to both the manufacturers of automobiles and the manufacturers of trucks.

However, it is not difficult to identify transactional difficulties that attend market exchange in these circumstances. Consider indivisible physical assets common to two or more production processes. While in many cases markets can be expected to work quite well as devices for selling the services of assets subject to indivisibilities, there are circumstances where transactional difficulties and hence market failure is to be expected. If the fixed asset is highly specialized and if the number of leasors or leasees is quite small, then markets for the services of the fixed assets may be extremely thin. Bilateral monopoly situations can then arise in which potential leasees may attempt to extract the quasi rents associated with the utilization of the leasor's fixed and specialized asset [Williamson (1975, 1979), Teece (1976), Klein, Crawford and Alchian (1978)]. In order to avoid these hazards intrafirm trading — that is multiproduct diversification — can be engaged. Internal trading changes the incentives of the parties and enables the firm to bring managerial control devices to bear on the transaction, thereby attenuating costly haggling and disruptions and other manifestations of non-cooperative behavior. Exchange can then proceed at lower cost and with higher returns to the participants.

Diversification offers similar advantages with respect to the indivisibilities associated with information. Because of the reasons identified in section 3 above, markets for information are often shot through with hazards, and internal organization has efficiency properties which markets cannot always replicate.

5. Limits to diversification economies

Scope economies obtained via diversification are clearly circumscribed. If they are based upon the transfer of knowhow into different markets, then while the value of the knowhow may not be impaired by repeated transfer, the costs of accessing it may increase if the simultaneous transfer of the information to a number of different applications is attempted. This is simply because of a congestion factor which may attend the transfer process. As mentioned above, knowhow is generally not embodied in blueprints alone: the human factor is critically important. Accordingly, as the demands for sharing knowhow increase, bottlenecks in the form of over-extended scientists, engineers, and manufacturing/marketing personnel can be anticipated. Congestion associated with accessing common inputs will thus clearly limit the amount of diversification which can be profitably engaged. However, if the transfers are arranged so that they occur in a sequential fashion, then the limits imposed by congestion are relieved, at least in part [Teece (1977)]. Of course, control loss considerations may eventually come into play, as they do with any large organization, but the establishment of a decentralized divisionalized 'M-form' structure is likely to keep control loss problems to the very minimum. In this regard it is important to note that diversification based on scope economies does not represent abandonment of specialization economies in favor of amorphous growth. It is simply that the firm's comparative advantage is defined not in terms of products but in terms of capabilities. The firm is seen as establishing a specialized knowhow or asset base from which it extends its operations in response to competitive conditions.

Just as scope economies associated with the sharing of proprietary knowhow will eventually be exhausted, so too will the scope economies associated with sharing an indivisible specialized asset. When the indivisible asset is fully utilized, no further gains from additional diversification are to be expected. In this regard it is apparent that the exogenous growth of the market will circumscribe the scope economies obtainable from sharing an indivisible specialized asset.

6. Some empirical evidence: The diversification of petroleum firms

6.1. General

This paper does not purport to develop a fully fledged theory of the multiproduct firm. Rather, the objective here is limited to explaining relationships between economies of scope and the scope of the enterprise. However, the notion that the existence of a generic knowhow base within the enterprise might drive diversification decisions would seem to warrant some attention at the empirical level.

The empirical evidence on diversification is extremely sketchy, but what little evidence exists seems to affirm the empirical relevance of the propositions advanced earlier. Gort has investigated relationships between diversification and primary industry characteristics. His study showed a positive and statistically significant relationship between diversification and the technical personnel ratio [Gort (1962, p. 138)], a measure of research intensiveness. Gort was also able to show an inverse relation between diversification and the rate of growth of the diversifying firm's primary (i.e., traditional) industry [Gort (1962, p. 140)]. These results seem to be supported by historical analysis. Chandler (1969, pp. 274–275), for instance, observes that 'the pioneers in the new strategy of diversification where those firms which had the technological and research skills to develop new products and the administrative experience to produce and distribute them at high volume for national and international markets'. Accordingly, the modern diversified enterprise is viewed as 'a calculated rational response of technically trained professional managers to the needs and opportunities of changing technologies and markets' [Chandler (1969, p. 279)].

The Chandler position appears to be consistent with Gort's results and the theory developed earlier. Furthermore, while his original focus was on the importance of technological and managerial considerations, Chandler's more recent findings indicate that other common inputs, especially marketing and purchasing knowhow, are also important. [Chandler (1977, p. 473).] While aggregate studies of these kinds are clearly useful in suggesting the relevance of the theory, a more microanalytic focus is needed. This is because the transactions cost approach focuses on the individual transaction, and the possible market failure considerations which may suggest diversification.

6.2. The petroleum industry

The petroleum industry, after decades of specialization within its traditional boundaries, has begun to diversify principally into alternate fuels (table 1). The process has been relatively recent, so that few petroleum firms derive more than a trivial portion of their earnings from the production of alternate fuels. Whether diversification here is based on monopoly or efficiency considerations has been an issue of open debate [Mitchell (1978)]. It is not the objective of this paper to resolve this issue. Rather, a much more limited purpose is engaged — simply to establish the plausibility of the hypothesis that one factor driving the diversification of petroleum firms into alternate fuels is the economies of scope which can be generated through the sharing of industry technological knowhow across fuels. Thus if the technological capabilities of petroleum firms can be shown to match the knowhow requirements of alternate fuels, than a prima facie case for scope economies will have been established. Furthermore, to the extent that technology transfer opportunities between petroleum activities and alternate fuels activities is likely to be recurrent rather than occasional, and the application specialized rather than non-specialized, a prima facie case for seeking non-market modes of transfer (specifically intra firm transfer) will also have been established. This is not of course to deny that other considerations — including monopoly power, managerial discretion, and regulation — may also be factors driving the diversification decisions of petroleum firms. Some of these issues are engaged in the appendix.

The task to be confronted now is the analysis of the extent to which petroleum industry technology is relevant to the production of alternate

Table 1

Participation of crude oil producers in other energy industries, USA, 1975.[a, b]

Company*	Ranked by net crude oil, condensate, and ngl production, 1976	Coal: Reserves	Coal: R & D	Coal: Production	Solar: Solar R & D	Nuclear fuel cycle: Uranium exploration and/or reserves	Nuclear fuel cycle: Uranium mining and milling	Nuclear fuel cycle: Conversion to uranium hexafluoride (uF_6)	Nuclear fuel cycle: Uranium enrichment	Nuclear fuel cycle: Conversion into uranium dioxide pellets (uO_2)	Nuclear fuel cycle: Fuel fabrication	Nuclear fuel cycle: Fuel reprocessing	Oil shale: Reserves	Oil shale: R & D	Geothermal: Exploration and/or reserves	Geothermal: R & D	Geothermal: Production	Tar sands**: Exploration and/or resources	Tar sands**: R & D	Tar sands**: Production
Exxon	1	X	X	X	X	X	X	0	0	0	X	0	X	0	0	0	0	X	X	0
Texaco	2	X	X	0	0	X	0	0	0	0	0	0	X	X	0	0	0	X	X	0
Shell	3	X	X	0	X	X	0	0	0	0	0	0	X	X	X	0	0	X	0	0
Std. Oil of Indiana	4	0	X	0	0	0	0	0	0	0	0	0	X	X	0	0	0	0	0	0
Gulf	5	X	X	X	X	X	X	0	0	0	X	0	X	X	X	X	0	X	0	X
Std. Oil of Calif.	6	0	0	0	0	X	0	0	0	0	0	0	X	X	X	0	0	X	0	0
Atlantic Richfield	7	X	X	0	0	X	X	X	0	0	X	X	X	X	0	0	0	X	0	0
Mobil	8	X	0	0	X	X	X	0	0	0	0	0	X	X	X	X	0	X	0	0
Getty	9	0	0	0	0	X	X	0	0	X	0	0	X	0	0	0	0	X	X	0
Sun	10	X	X	X	X	X	0	0	0	0	0	0	X	X	X	X	0	0	X	X
Union	11	0	X	0	0	X	0	0	0	0	0	0	X	X	X	X	X	X	0	0
Phillips	12	X	X	0	0	X	0	0	0	0	0	0	X	X	X	0	0	X	0	0
Continental Oil	13	X	X	X	0	X	X	0	0	0	0	0	X	0	0	0	0	X	0	0
Cities Service	14	0	0	0	0	X	0	0	0	0	0	0	X	X	0	0	0	X	0	X
Marathon	15	X	0	0	0	X	0	0	0	0	0	0	X	X	0	0	0	0	0	0
Amerada Hess	16	0	0	0	0	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tenneco	17	0	0	0	0	X	0	0	0	0	0	0	X	0	0	0	0	X	0	0
Louisiana Land	18	0	0	0	0	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pennzoil	19	0	0	0	0	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Superior	20	X	0	X	0	0	0	0	0	0	0	0	X	X	0	0	0	0	0	0
Union Pacific	21	X	0	X	0	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Santa Fe Industries	22	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R.J. Reynolds	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	X	0		0
International Paper	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kerr-McGee	25	X	X	0	0	X	X	X	0	X	X	X	0	0	0	0	0	0	0	0
Std. Oil Ohio	26	X	X	X	X	X	0	0	0	0	0	0	X	X	0	0	0	X	0	0
General American Oil of Texas	27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ashland	28	X	X	X	0	X	0	0	0	0	0	0	X	X	0	0	0	0	0	0
American Petrofina	29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diamond Shamrock	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

[a] An asterisk indicates companies ranked by 1975 crude oil and ngl production. Assignments do not include joint venture activities (except in research) unless the specified firm has more than 50 per cent of the equity in the joint venture. Two asterisks indicate that Canada is included. X indicates current involvement. 0 indicates no current involvement.

[b] *Source:* Annual reports, questionnaire data, and interviews with corporate executives.

Table 2

The complementary nature of technological inputs used in petroleum and alternate fuels.

Process	Resource development	Resource extraction	Transportation	Resource processing	General
Petroleum technology	(1) Exploration techniques — geological — geophysical (2) Data bank information	(1) Well-drilling technology (2) Formation fracturing methods (3) Reservoir engineering technology	Pipeline technology	(1) Petroleum refining technology (2) Mathematical modeling	(1) Materials science (2) Engineering skills (3) Chemical engineering expertise (4) Plant health and safety experience
Alternate fuels to which petroleum technology is applicable	(1) Coal (2) Uranium (3) Geothermal (4) Oil Shale	(1) Oil Shale (2) Coal (3) Geothermal (4) Uranium	Coal (slurry pipelines)	(1) Coal (2) Oil Shale	All alternative energy sources

fuels. Table 2 summarizes the nature of technological transfer opportunities between petroleum and alternative primary energy sources. Thus, with respect to resource development, most alternate fuel ventures (except for solar development) first require the location and delineation of a mineral resource. In locating alternate fuel sources such as coal, oil shale and uranium, exploration techniques developed by the petroleum industry are often useful. Mineral deposits are found in sedimentary formations similar to oil and gas bearing formations, so that geological and geophysical expertise is valuable. For example, geophysical techniques developed for oil and gas exploration (such as wire-line well logging) have been directly applied to the location and definition of deposits of lignite coal. Similarly, uranium deposits can be identified by classical techniques used in oil exploration. In exploring for geothermal energy, sources can be located and identified using geophysical techniques such as electromagnetic, seismic and gravity methods. Computer-assisted evaluation of geophysical data, pioneered by the oil industry, can facilitate the interpretation of geopressure levels and other data. Tying the results of mineral exploration together is a comprehensive data bank accumulated by oil companies from their exploration activities, including data highly valuable to the search for alternate fuels.

In the field of resource extraction the same techniques are also used in the recovery of a number of different fuels. For instance, technology developed in the petroleum industry can be used directly or with modification in geothermal energy recovery and for *in situ* production of shale oil and coal fluids. Dry rock geothermal energy recovery, now being investigated as a potential production technology, will require extensive utilization of petroleum technology, including hydraulic fracturing and sophisticated directional drilling. *In situ* coal or oil shale production, requiring a large number of closely spaced wells, draws largely on well drilling experience derived from petroleum exploration and development. In addition, the operation of an *in situ* process requires detailed knowledged of fluid and heat flow that is common to the extensive reservoir engineering knowledge developed in connection with oil production.

Similar examples abound in the area of resource processing. Coal conservation and shale oil recovery can involve extensive application of conventional refining technology and extensions of existing processes, so much so that in many respects a coal or shale oil conversion plant may have a number of features in common with an oil refinery. High temperature and high pressure treatment of hydrocarbon fluids, catalytic processing of hydrocarbons, fluidized bed design and hydrogenation processes, as well as conventional separation processes have applications common to oil processing in coal conversion and shale oil recovery. Indeed, many scientists believe that developments in the science of catalysis — a critical science to petroleum refining — will be the key to whether gasoline can be made economically from coal.[7] Also worthy of special mention is the considerable technology developed for treating and handling liquid waste streams. Especially important is the removal of sulfur, a problem in the forefront of many current developments in petroleum technology. The significance of these generic similarities becomes even more apparent when attention is focused on the specific fuels identified below.[8]

In the later stages of the nuclear fuel cycle, technological complementarities with the petroleum industry are apparent. Conversion of ore to uranium oxide, uranium hexafluoride, or uranium metal, and the processing of spent fuel utilizes processing techniques such as solvent extraction, distillation and physical separation similar to those encountered in petroleum processing.

Although technological complementarities can be identified between oil production and coal production, they are not pervasive, and little oil-related technology has actually been applied to coal mining operations.[9] Nevertheless, there are some technological complementarities which can be identified. In areas such as hydrology, slurry transport,[10] and deposit delineation, combinations of mining and petroleum technologies can lead to

[7]See, for example, 'More Catalysts Are Sought to Curb Costs and Tap New Sources of Raw Materials', Wall Street Journal, July 9, 1978. This article speculates that if the right catalysts are developed, gasoline producers may someday be able to do without crude oil.

[8]The minerals exploration field also offers considerable opportunities for oil companies to use the exploratory data which they have on file, plus their geological, geophysical, and land development skills. Discoveries of sedimentary mineral deposits are sometimes made as a byproduct of oil and gas exploration. For instance, all three major potash producing areas of North America were encountered as a result of oil exploration activity. Geophysics and well logging are the critical skills that oil companies can bring to the mineral area. This explains, at least in part, the timing of the oil industry's movement into minerals. Experts agree that most mineral deposits easily discernible by surface exploration have already been found. Accordingly, the major opportunities for future discoveries are believed to lie in hidden subsurface deposits. The exploratory techniques used in oil and gas are applicable to this task since these techniques are designed to identify either subsurface conditions favorable to deposits, or to identify actual deposits. Various logs run in the normal course of oil well drilling can also help identify mineral deposits. But the technological spillovers between oil and minerals are not confined to exploration. Oil field knowhow, for instance, is relevant to a number of mining methods. This is not to claim that there are not important differences between oil and gas and minerals exploration expertise. For instance, minerals expertise depends on our understanding of the complexities of igneous and metamorphic geology whereas oil and gas exploration requires knowledge of sedimentary geology.

[9]There have been some exceptions in underground mining operations. Underground operations involve the hazards and problems inherent in tunneling, such as methane gas drainage, control of roof falls, and feasibility studies of long wall mining. Many of these activities can involve core or directional drilling, logging, fracturing, pipelining, and putting acoustic signals through the earth — all of which are operations which have been developed by the petroleum industry. See 'Technical Aspects of Petroleum Company Expansion into Coal: the Case History of Conoco and Consol' (Ponca City, Continental Oil Company, R & D Department, May 1976, p. 3).

[10]Conoco's Coal Slurry Transport System is a very good example of technology transfer from petroleum to coal. The coal slurry pipeline (Slurry Transport System) replaces conventional shuttle cars, which cannot keep up with modern continuous mining machines, and does not require finely ground and sized coal as do other slurry pipelines. Console built on its background

improved operations. However, major complementarities lie in R & D. Oil refinery technology finds much direct application in coal conversion since the techniques used in the design, construction, and operation of refineries and petrochemical plants are applicable. More specifically, petroleum industry experience in high pressure, catalytic hydrogen process (central to coal liquefaction) can be used.

The discovery and harnessing of geothermal energy involves a multidisciplinary approach which is not just confined to exploration and production research. The well drilling, well completion, and handling of produced fluids for disposal are problems drawing on conventional drilling and production expertise. Geophysical research is involved in improving the ability to locate desirable geothermal energy sources without drilling. Also, the exposure of materials to temperatures and fluids results in corrosion and erosion problems not unlike those encountered in oil refining and transportation. Problems in developing steam reservoirs require research efforts by chemical engineering specialists such as those with a background in refining. In addition, the special chemical analyses required to permit the definition of what is happening as high temperature fluids are produced requires specialized analytical talents available at present only to the large oil companies.[11]

Technological complementarities also exist with respect to extracting oil from shale. The location and extraction of shale rests on some of the technology relevant to oil exploration and production, while retorting shale involves the utilization of technology not altogether alien to refining technology. An excellent illustration of the potential benefit is the petroleum industry concept for improved oil shale retorting. This concept is an extension of fluidized catalytic cracking technology practiced in major refineries. Once oil is produced from shale, the storage and transportation problems are the same as those encountered with conventional crude.

It is also apparent that the transfer opportunities identified are not of the one shot kind. Opportunities for continuous transfer abound. It is not that there is a fixed stock of knowhow to be transferred once and for all. In catalysis, for instance, new developments are constantly emerging and continuous sharing and recurrent transfer is needed for the successful development of alternate fuels. Applying the paradigms of section 3, intrafirm transfer would appear to provide the most efficient vehicle for capturing the

in pipelining petroleum coke and phosphate rock to create the technology necessary to pump coarse coal slurries. (See 'Technical Aspects of Petroleum Company Expansion into Coal', pp. 4-5.)

[11] It is not surprising that Union Oil was, along with Magma and Thermal, a primary party in the initial successful commercialization of energy production from geothermal sources. An investigation of this particular case reveals the extensive complementarities that exist between petroleum and geothermal industries in exploration, development, and production.

scope economies available through the utilization of petroleum industry technology in the production of alternate fuels. The requisite transfers involve recurrent transfer of proprietary knowhow to a specialized application. But the advantages from diversification must of course be balanced against the control loss and other costs identified in section 5 before it would be possible to present an overall assessment of the efficiency properties of petroleum firm diversification across alternate fuels.

7. Public policy implications

Since diversification is a salient characteristic of the modern enterprise, the efficiency with which firms allocate resources internally in contrast to how they might have been allocated by the market becomes a topic of considerable importance. Yet there have been few attempts to examine the internal efficiency properties of the diversified enterprise. Much of the attention has gone to examining relationships between diversification, growth, and competition [Gort (1962), Berry (1975), Utton (1979)].

Recent developments in the theory of scale and scope economies and interproduct complementarities have sharpened understanding of some of the fundamental concepts involved in multiproduct production. However, this literature is seriously flawed insofar as it attempts to derive organizational implications directly from industry cost functions. Economies of scope are neither necessary nor a sufficient condition for cost savings to be achieved by merging specialized firms. But if economies of scope are costly to capture because of the transactional difficulties surrounding the sharing of a common input, then multiproduct organization is likely to yield compelling efficiencies.

Accordingly, if public policy towards the business enterprise is to be fashioned with efficiency as the objective, then it is necessary to consider transactions cost as well as technological issues. Proposals for the divestiture or amalgamation of industries requires a sensitive treatment of both technological and transactions costs considerations. Empirical studies of the kind proposed by Baumol and Braunstein do not suffice [Baumol and Braunstein (1977)] if delineating organizational boundaries for the business enterprise is the issue at hand. The implications for antitrust policy are quite clear. The courts must be sensitive to transactions cost as well as technological issues.

8. Conclusion

By engaging transactions costs analysis in the fashion suggested by Williamson, the relationships between economies of scope and the scope of the enterprise have been clarified. The basic conclusion is that economies of scope do not provide a sufficient raison d'être for multiproduct firms. There are likely to be numerous instances where economies of scope can be captured by an economy of specialized firms contracting in the marketplace for the supply of common inputs. Nevertheless, there are important instances where multiproduct firms will be needed to capture scope economies. Two circumstances were examined in some detail: (1) where the production of two or more products depends upon the same proprietary knowhow base and recurrent exchange is called for, and (2) when a specialized indivisible asset is a common input into the production of two or more products. Under circumstances (1) and (2), integration (that is, multiproduct organization) is likely to be an efficient mode of organization.

Appendix

The purpose of this appendix is to investigate whether efficiency considerations, including economies of scope, might help explain the recent diversification of petroleum firms into alternate fuels. Section 6.2 above showed that petroleum industry technology was relevant to the production of alternate fuels. In this appendix we search for empirical manifestations of this and other synergistic effects.

As a theoretical matter, a business strategy which captures efficiency gains will enhance firm performance. However, in competitive markets the enhanced performance of more diversified firms will not be observable to the extent that diversification is an adaptive strategy designed to offset prospective long-run earnings declines from traditional markets [Weston and Mansinghka (1971)]. Hence, at least in the early stages of diversification, no interfirm differences in profitability are to be expected amongst firms displaying different levels of diversification. Even at a more advanced stage, interfirm differences in profitability may not be observable. Consider, for instance, two firms with similar levels of oil and gas reserves in period one and the same zero level of diversification. Suppose that one firm suffers declining reserves of oil and gas and, to offset the associated decline in investment opportunities and prospective profits, it diversifies while the other firm does not. Diversification for this firm may simply result in the maintenance of earnings in period two. In period two the two firms will display different levels of diversification but the same risk-correlated level of profits. Hence, no empirically observable relationships between diversification and profitability is postulated, since diversification has merely protected profits. These considerations suggest that there is little to be gained from trying to test the implications of the efficiency hypothesis by examining differences in accounting profits or market returns for firms with different degrees of diversification. An alternative, but albeit indirect approach is to examine predictions with respect to the level of individual firm diversification.

In order to predict the efficient level of firm diversification, attention must be focused on life cycle considerations [Penrose (1959), Mueller (1972)]. If knowhow, capital, and other common inputs into the production of various fuels can be fully employed in the petroleum business, there are likely to be at best only minimal scope economies attached to diversification. This will be the case in the early phase of a firm's life cycle [Penrose (1959)]. In the early stages of industry development, firms that are successful at finding oil begin accumulating profits. As long as above average growth expectations hold, managerial and stockholder objectives both indicate reinvestment of the cash flows. However, as the firm's oil and gas reserves decline, investment incentives will change [Grabowski and Mueller (1975)]. The profitability of further investment to exploit the original discoveries declines, the cost of making additional discoveries increases, and the market for the product may also exhibit slower growth. In addition, the imitative behavior and exploratory success of other firms in a competitive industry will drive profits down. Because of these considerations, firms will reach a point where they are unable to reinvest profitably a good portion of their cash flows in the traditional lines of business. In these circumstances, profit maximizing firms will repurchase stocks if there is no alternative use for the firm's underutilized assets. Otherwise, diversification into other endeavors will be indicated as scope economies can be realized. This suggests that the larger the petroleum firm's cash flow from oil and gas *in relation to reinvestment opportunities*, which are to be proxied here by the firm's worldwide reserves of oil and natural gas liquids,[12] then the greater the degree of diversification which it could be expected to exhibit. Hence the efficiency hypothesis predicts a relationship of the following kind between a petroleum company's normalized cash flow and the degree of its diversification:[13]

$$D_{it} = f(C_{it}/R_{it}) \quad \text{where} \quad \frac{\partial D_{it}}{\partial (C_{it}/R_{it})} > 0.$$

[12] Worldwide reserves of oil and natural gas liquids are a proxy for reinvestment opportunities since investments must be put in place to extract the oil, especially if it is offshore or if secondary and tertiary recovery techniques have to be used. The firm's level of reserves also proxies, in a rough sense, past exploratory success. Past exploratory success, in turn, is often a good proxy for the firm's exploratory skills, and a firm with a comparative advantage at exploration is likely to find advantage in investing in further exploratory efforts. Because of the sporadic nature of discoveries (and nationalizations!), it would appear that the stock of reserves — rather than the increments in a recent period — is the better proxy for reinvestment opportunities.

[13] An important question arises as to the appropriate lag structure, if any, to specify for this model. Is it that diversification decisions are made prospectively, retrospectively, or con-

D_{it} is a measure of the diversification of the ith firm in year t, C_{it} is the level of cash flow from oil and gas activities of the ith firm in year t,[14] and R_{it} is the level of the ith firm's oil and gas reserves in year t.

Besides reinvestment opportunities in relation to cash flow, the existence of opportunities for sharing technological knowhow across fuels is also hypothesized to promote diversification within the energy industries. Opportunities of this kind are based on the existence, within petroleum companies, of technological and research skills applicable to alternate fuels. (section 3 above). Assuming that the firm's cumulative R & D expanditures over the previous decade (normalized by sales) are a proxy for the firm's stock of relevant transferable knowhow,[15] then

$$D_{it} = f\left(\sum_{t=1}^{n} RD_{it}/S_{it} \right) \quad \text{where} \quad \frac{\partial D_{it}}{\partial \left(\sum RD_{it}/S_{it} \right)} > 0.$$

R_{it} is the ith firm's applied research and development[16] expenditures on oil and gas in year t and S_{it} is the firm's dollar value of sales[17] in year t.

Diversification is also facilitated if the firm has adopted an M-form multi-divisional internal structure.[18] The M-form structure functions as an ideal

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temporaneously with variations in the firm's cash position relative to reserves? The assumption made here is that the firm can predict its reserves and cash flow reasonably accurately within the time frame needed to decide and effect a diversification decision. Accordingly, in anticipation of an increase in its cash to crude oil reserve position, a firm can plan ahead so that lateral investment decisions occur contemporaneously with increases in the cash to reserve ratio. The assumption does not call for lagging or leading the independent variable.

[14]SEC reporting requirements for 1975 did not require the disaggregation of cash flow data unless profits from the line of business accounted for 10% or more of the firm's income. Accordingly, cash flow from oil and gas is proxied by the firm's total cash flow. It turns out that for 1975, cash flow from other energy activities accounted for a zero or trivial proportion of total cash flow in all but two of the sample firms, Kerr McGee and Continental Oil. In order to avoid possible simultaneity bias, these firms were removed from the sample.

[15]Research experditures are summed over the past ten years to proxy for the firm's total stock of knowhow.

[16]Applied research and development expenditures, rather than total R & D expenditures, are utilized to avoid a possible simultaneous equation bias. Nelson (1959), for example, argues that firms' basic research expenditures are a function of their diversity. In order to avoid this source of potential statistical bias, basic research expenditures are omitted from the R & D variable used.

[17]R & D is normalized by sales to control for possible size related impacts on diversification.

[18]Many large corporations have adopted multidivisional internal structures in response to increasingly complex administrative problems encountered as firm size and the diversity and magnitude of the firm's activities increased. With the formation of quasi-autonomous operating divisions organized along product, brand, or geographic lines, rather than along functional lines, strategic and operating decision making can be separated, divisional objectives consistent with corporate goals can be more easily specified and coordination requirements effectively attenuated. The multi-divisional form allows tasks to be broken down and assigned to divisions in which the functional form is again the most efficient structure. A particular form of the multi-

takeover agent, and is also well suited for managing diverse operations in a decentralized fashion. As Chandler (1977, p. 475) has observed, 'the multidivisional structure ... institutionalized the strategy of diversification'. This suggests that[19]

$$D_{it} = f(\mathrm{d}M_{it}),$$

where $\mathrm{d}M_{it}$ is a dummy variable to represent the M-form structure.

The model suggested by these considerations is the following:[20]

$$D_{it} = \alpha_0 + \alpha_1 \frac{C_{it}}{R_{it}} + \alpha_2 \sum_{t=1}^{n} RD_{it}/S_{it} + \mathrm{d}M_{it} + z_i, \tag{1}$$

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divisional structure, a genre called the M-Form, has a well delineated and properly functioning control structure that induces appropriate goal pursuit by the divisions. There are several essential attributes associated with such control systems. First, there must be an explicit definition of an objective function, usually in terms of a profit or rate of return measure. Second, there must exist incentive machinery within the firm that induces division managers to maximize with respect to the specified objective function. The precise form of such machinery may vary considerably. Most obvious is the use of bonuses or salary raises which are tied to division performance. However, less formal devices may also be effective. For example, promotions (and the accompanying boost in status) or even more direct contact/communication with superiors following positive performance results; and/or demotions or transfers following unsatisfactory performance are frequently considered to provide effective incentive machinery (particularly for management personnel). Regardless of the exact form of the incentive devices, a key factor in assuring their effectiveness is the continuous monitoring (through internal information audits) of division performance by the centralized executive management (which itself may be an effective informational control system) with corrective action being taken when results dictate [Williamson (1975, pp. 145–146)]. The existence of these control systems serves the purpose of attenuating the internal control loss encountered by the management of a functionally organized firm as it expands. A classification of the internal structure of the largest petroleum firms is presented elsewhere [Armour and Teece (1978)].

[19] Possible simultaneous equation bias will exist if diversification also drives internal structure. The theory with respect to the determinants of the internal structure of the firm is not well developed. However, to the extent that diversification might possibly drive internal structure, the lags involved can be expected to be quite long, and and the magnitude of any specification bias might therefore be expected to be quite small. Furthermore, there are no examples in the petroleum industry where reorganization to an M-form has occurred simultaneously with the acquisition of assets in alternative fuels. With a few exceptions most investments in alternate fuels by petroleum companies are generating a level of earnings which is zero or trivial in relation to the firm's total earnings.

[20] The proposed model is subject to the limitations of a single equation approach, as noted in the previous footnote. The equation specified may be only one equation in a system of simultaneous equations in which diversification, internal structure, and R & D are jointly determined. However, it may be realistic to view such a system as recursive. That is, although there may be feedbacks in the system, the associated lags may be sufficiently long to permit one to pull out individual equations for separate treatment. In any case, this is what is done in the present investigation. The lack of data leaves no alternative.

where D_{it} is the level of diversification of the ith petroleum firm across various energy activities[21] in year t, R_{it} is the worldwide crude oil and natural gas liquids reserves[22] of the ith firm in year t (measured in millions of barrels), C_{it} refers to the cash flow of the ith firm in year t[23] (measured in millions of dollars), RD_{it} refers to the ith firm's expenditure on applied research and development on oil and gas in year t[24] (measured in millions of dollars), S_{it} refers to the ith firm's sales in year t (measured in millions of dollars), dM_{it} is a dummy variable which is assigned a value of one if the firm has an M-form structure,[25] and a value of zero otherwise, Z_{it} is a random error term for the ith firm (Z_{it} is assumed to be normally distributed with constant variance).

In order to estimate the equation data were assembled for the oil producers in Fortune's 500.[26] Firms for which it was not possible to obtain reserve data for 1975 were eliminated from the sample, leaving a total of 24 firms.[27] The model was estimated for 1975 for the important reason that 1975 was late enough to observe a degree of diversification by some firms (there was very little even as late as the mid '60's) yet early enough to avoid possible simultaneity problems from the influence of diversification on oil and gas reserves, cash flow, sales, and applied research and development expenditures. However, since two of the sample firms — Kerr McGee and

[21]The following energy activities were identified: holding coal reserves; coal production; uranium exploration and/or reserve holdings; nuclear fuel fabrication; oil shale exploration and/or reserve holding; geothermal exploration and/or reserve holding; geothermal energy production; tar sand exploration and/or reserve holding; tar sand production. Information on which of these activities firms in the sample were engaged in in various years was gleaned from annual reports, 10K's and from questions submitted to the firms themselves. In each case the final assignments were verified by the firms in the sample. For each of the activities in which the firm was engaged, it was assigned a score of 1. The variable D_{it} therefore represents the summation of these scores for the ith firm in 1975. Unfortunately, this variable does not take into account the relative importance of the various fuels nor the degree to which each firm is involved in the identified activities. Hence, it is rather a crude measure of diversification but it is more refined than all the alternatives so far developed on a comprehensive basis. Lack of data prevents further refinements at this time.

[22]Reserve data were obtained from John Herald, Inc., *Annual Petroleum Outlook and Oil Industry Comparative Reports* (John Herald, Inc., Greenwich).

[23]The cash flow data were obtained from the 19..-1975 Compustat Annual Industrial Tape prepared by Investors Management Sciences, Denver, Colorado.

[24]This data was obtained from a questionnaire survey conducted by the author. The definitions of research and development, and the various components thereof, are those specified by the National Science Foundation. A summary of these data can be found elsewhere [Teece and Armour (1977)].

[25]A firm is classified as having an M-form structure if it meets the general criteria outlined in the appendix to Armour and Teece (1978, pp. 120–121). The identification of the M-forms firms in the sample can also be obtained from Armour and Teece (1978, p. 120, Table A1).

[26]In addition, the General American Oil Company was added since data were readily available.

[27]These firms were Amerada Hess, American Petrofina, Ashland, Arco, Cities Service, Continental, Exxon, General American, Getty, Gulf, Kerr McGee, Marathon, Mobil, Occidental, Pennzoil, Phillips, Shell, Socal, Standard of Indiana, Sohio, Sun, Superior, Texaco and Union.

Continental Oil — had a non-trivial proportion of their earnings accounted for by alternate fuels they were excluded from the sample to avoid possible simultaneity bias. The estimated equation for the level of diversification in 1975 was

$$D_i = \underset{(0.30)}{0.59} + \underset{(2.47)}{2.87}\ C_i/R_i + \underset{(2.31)}{20.03} \sum_{t=65}^{75} RD_{it}/S_t + \underset{(2.15)}{1.64}\ dM_i,$$

$$R^2 = 0.41, \quad \bar{R}^2 = 0.38, \quad n = 22, \quad \text{S.E.} = 3.071.$$

All of the variables carry the postulated sign and are statistically significant at the 95% level. Apparently, normalized cash flow (normalized, that is, by a proxy for reinvestment opportunities), technological intensity, and organizational structure all have a statistically significant association with the number of identifiable energy activities into which petroleum firms have diversified.

It appears from these results that life cycle and efficiency considerations explain some part of the economic reality that has driven petroleum firms into alternate fuels. However, the model explains only a modest portion of the variability observed, indicating that a wide range of other considerations has played upon diversification decisions. Still, it is of some import that efficiency related variables do have some predictive power.

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