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# Price uncertainty and vertical integration: an examination of petrochemical firms

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**Abstract**

The petrochemical industry employs assets subject to temporal and site specificity. The OPEC oil price shocks of the 1970s made it difficult to write contracts covering business dealings in the industry. I use this production and economic setting as a natural experiment to test transaction cost theory. In support of the theory, I find that input price uncertainty in the 1970s positively affected the extent of vertical integration by firms into input stages. Moreover, the positive reaction of vertical integration to price uncertainty mainly occurs in transactions subject to asset specificity. I also examine price controls and market power as alternative explanations for vertical integration in the industry, but fail to find support for these hypotheses. © 2000 Elsevier Science B.V. All rights reserved.

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## 1. Introduction

In his presidential address to the American Finance Association, Jensen (1993) asserts that the OPEC oil price shocks in the 1970s and the associated ten-fold increase in oil prices have had far-reaching implications on corporate structure. He further pinpoints that the wave of mergers and restructuring in the 1980s actually began in 1973, the year of the first oil price shock. In support of the Jensen's thesis, Mitchell and

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Mulherin (1996) find that industry shocks affect merger and restructuring activities. In this paper, I provide further refinement of this argument through a microanalytic treatment of Jensen's insights within a particular industry. I analyze and empirically test several hypotheses pertaining to the causes of vertical integration in the petrochemical industry. The period of study is the 1970s during which two oil price shocks induced high input price uncertainty in the industry. I examine how increased price uncertainty affects the extents of input self-sufficiency by petrochemical firms. Within the petrochemical industry, abundant prior evidence suggests that major operational restructuring took place subsequent to the oil price shocks.[1] The time period and the industry together provide a natural experiment to test how an organization adapts its structure to economic changes.

The transaction cost theory of Williamson (1971, 1975, 1979) and Klein et al. (1978) maintains that vertical integration is a response to asset specificity caused by specialized investment that has lower value outside a given transaction. If a contract is drawn to govern the transaction, the specialized investment creates an ex post bilateral bargaining situation in which opportunistic rent seeking, or holdup, by the transactors may occur. Vertical integration is proposed as a solution to the holdup problem, because the possibility of holdup is suppressed under the common ownership. The theory also emphasizes that uncertainty is a necessary condition for asset specificity to influence organizational structure. Without uncertainty, a perfect contract can be written to safeguard the transaction; hence, there is no need for vertical integration. By the same token, given the existence of asset specificity, vertical integration will react positively to an increase in uncertainty.

Prior empirical tests of the transaction cost theory have focused on asset specificity. Consistent with the theory, these studies generally find that vertical integration increases with asset specificity. Relatively less evidence is available on the role of uncertainty. Relevant to the current paper, several studies examine the effects of the oil price shocks on contract provisions (Goldberg and Erickson, 1987; Crocker and Masten, 1988, 1991). These studies document decreases in contract length, more frequent price adjustment and renegotiation for long-term contracts in the petroleum coke and natural gas industries after 1973.

As a complement to prior research, I compare the relative advantage between vertical integration and contract governance in the petrochemical industry during the 1970s. The industry is marked by substantial asset specificity. I examine whether firms embark on vertical integration to avoid holdup problems in supply contracts, which are exacerbated by high price uncertainty. I also test the hypothesis that the degree of the impact of price uncertainty on a firm's extent of vertical integration varies systematically with the degree of asset specificity. To capture asset specificity in the industry, proxy variables are constructed for the input substance and industry agglomeration. Lastly, I examine two alternative explanations for vertical integration in the industry. One possibility is

[1] See Bower (1986), Spitz (1988), Stobaugh (1988), Chapman (1991), Lane (1993), and Arora and Gambardella (1998).

that firms integrate vertically to circumvent price controls. Another possibility is that the firms integrate vertically to exercise market power.

The findings in this paper are generally consistent with the predictions of the transaction cost theory. I find strong evidence from the 1970s that input price uncertainty and asset specificity jointly affect vertical integration in the industry. In contrast to this general consistency with transaction cost theory, my evidence fails to support the price control or the market power hypotheses.

The remainder of the paper is organized as follows. Section 2 discusses the theory and related prior evidence. Section 3 provides an overview of the industry, including sources of asset specificity, contracting problems in the 1970s, and cases of organizational responses. Section 4 reports empirical results. And Section 5 concludes the study.

## 2. Theory and related prior evidence

There are many potential explanations for vertical integration, including risk aversion (Blair and Kaserman, 1978),[2] price inflexibility (Carlton, 1979),[3] price controls (Stigler, 1951), and market power.[4] In his early work on the nature of the firm, Coase (1937) focuses on transaction costs: vertical integration is used when the costs of market transactions exceed the costs of internal organization. This section discusses the transaction cost theory and evidence. The applicability of the theory to the petrochemical industry will subsequently be examined and compared with alternative explanations in the section on empirical analysis.

### *2.1. The transaction cost theory*

Much of transaction cost analysis emphasizes asset specificity. Specialized assets, because of their limited exchange opportunities outside a given transaction, create quasi-rents that are subject to expropriation by parties in the transaction. The higher the degree of asset specificity, the larger the quasi-rents at stake, and hence the higher the holdup incentive. As the holdup problem becomes severe, a contract may not be sufficient to safeguard the transaction. Williamson (1971, 1975, 1979) and Klein et al. (1978) posit that vertical integration is one solution to the holdup problem, because

[2] Producers at two stages of production may merge their operations to reduce total risk, providing that returns at the two stages are negatively correlated. The application of the risk aversion hypothesis is limited, as it relies on the assumption that capital markets are imperfect in that stockholders can not fully diversify away the risk by forming portfolios.

[3] The cited study by Carlton shows that quantity risk caused by inflexible prices can induce vertical integration. Firms with relatively stable input requirements may integrate into input production to avoid paying a premium for the input that is induced by the fluctuating demand by other buyers. Lieberman (1991) finds support for this hypothesis in the chemical industry.

[4] There are a number of ways that a firm may gain market power through vertical integration. Several widely discussed sources of market power include foreclosure, price discrimination, and entry barriers. See Perry (1989) for a survey.

unified ownership suppresses the holdup possibility.[5] Several types of asset specificity have been discussed in the literature: site specificity, physical asset specificity, human capital specificity, and dedicated assets (Williamson, 1985). In addition, temporal specificity refers to transactions whose performance depends on timing, while the technology and the assets involved are quite common in nature (Masten et al., 1991; Pirrong, 1993).

Although asset specificity is important, the transaction cost theory stresses that uncertainty is a necessary condition for asset specificity to induce vertical integration. The idea is simple. Without uncertainty, a perfect contract covering full contingencies can be written. There is no possibility of holdup, hence no need for vertical integration. In an analysis of contract choices, Klein (1992, 1996) shows that, in the face of uncertainty, a contract will be designed to reduce holdup probability as well as the potential gain from the holdup. Two recent studies elaborate on that idea (Klein and Murphy, 1997; Baker et al., 1997). Both predict that vertical integration will be used when markets are highly uncertain. High price uncertainty implies a high possibility that a market price will fall outside a contract's self-enforcement range in its own terms along with the transactors' reputation capital, resulting in holdup and costly renegotiation. Because vertical integration eliminates the holdup possibility, a positive reaction of vertical integration to price uncertainty is expected.

The self-enforcement analysis also predicts the direction of vertical integration, i.e., who will be the owner and who will be the non-owner. In vertical integration, the party with more reputation capital is more likely to be the owner while the party with less reputation capital is more likely to be the non-owner. By giving the residual rights to the party with better reputation, the expected gains from holdup are reallocated from the party with poorer reputation to the other party with better reputation. This arrangement reduces the probability of holdup, as each party's expected gains from holdup now more closely coincide with his/her reputation capital.

### *2.2. Prior evidence*

Prior empirical research[6] on vertical integration focuses on the cross-sectional analysis of asset specificity. Various types of asset specificity have been reported to increase vertical integration in a variety of industries[7] as well as in several cross-industry studies.[8] Evidence on the role of uncertainty is less extensive and mostly based on

[5] Grossman and Hart (1986) emphasize that asset ownership in vertical integration is the primary reason that the holdup problem is solved. The owner of the asset is entitled to all contractually unspecified residual rights, which means the holdup problem and the associated investment inefficiencies can be minimized.

[6] See Shelanski and Klein (1995) for a survey of the empirical literature.

[7] A partial list of the industries includes automobile (Monteverde and Teece, 1982), aluminum (Stuckey, 1983), aerospace (Masten, 1984), electricity generation (Joskow, 1985), natural gas (Mulherin, 1986b), chemical (Lieberman, 1991), and pulp and paper (Ohanian, 1994).

[8] See Levy (1985) and Cave and Bradburd (1988). See also Spiller (1985) and Weiss (1992) in the context of vertical mergers.

survey data.[9] Worth noting are several papers examining the effects of the oil price shocks on contract provisions. Goldberg and Erickson (1987) study petroleum coke contracts and report that the sudden increase in price volatility after 1973 resulted in contracts of shorter duration and easier termination. Crocker and Masten (1988, 1991) study natural gas contracts and find that the duration of these contracts decreased following 1973. None of these papers studies vertical integration. However, Goldberg and Erickson conjecture that price shocks increased the advantage of vertical integration relative to long-term contracts. The premise is that shortening the contract length is not necessarily a remedy for transactions involving asset specificity, because frequent bargaining at contract renewal time incurs deadweight losses.

Another potential contractual response to price shocks is the use of price indices. To reduce the probability of holdup due to price changes, contract prices can be indexed to input prices, labor costs, or demand factors. However, price indices are not attractive when their relations with the values of the underlying products are variable. Goldberg (1985) studies the court dispute between Alcoa and Essex on their long-term contract on aluminum in the 1970s. He finds that the main problem is that the price indices in the contract did not track changing production costs and demand for aluminum, which were both soaring after 1973. Mulherin (1986a) reports that only 2% of natural gas contracts written during the 1940s and 1950s had price escalators based on a general index; the price adjustment of the remaining contracts was based on renegotiation. He explains that the general index was not used because the price of natural gas did not have a defined correlation with the general economy. Goldberg and Erickson document more extensive uses of price indices in post-1973 petroleum coke contracts, compared with pre-1973 contracts. However, it is pointed out that the price indices were not meant to ensure automatic price adjustment for the life of the contracts but only to provide a reference point for renegotiation. In a study of coal contracts, Joskow (1988) finds that it is difficult for indices to track large short-term changes in coal prices associated with demand or supply shocks. The celebrated case of Fisher Body versus General Motors (Klein et al., 1978; Klein, 1988) also demonstrates this point. General Motors could not avoid the opportunistic behavior of Fisher even though a sophisticated price-indexed contract had been designed to avoid the problem.

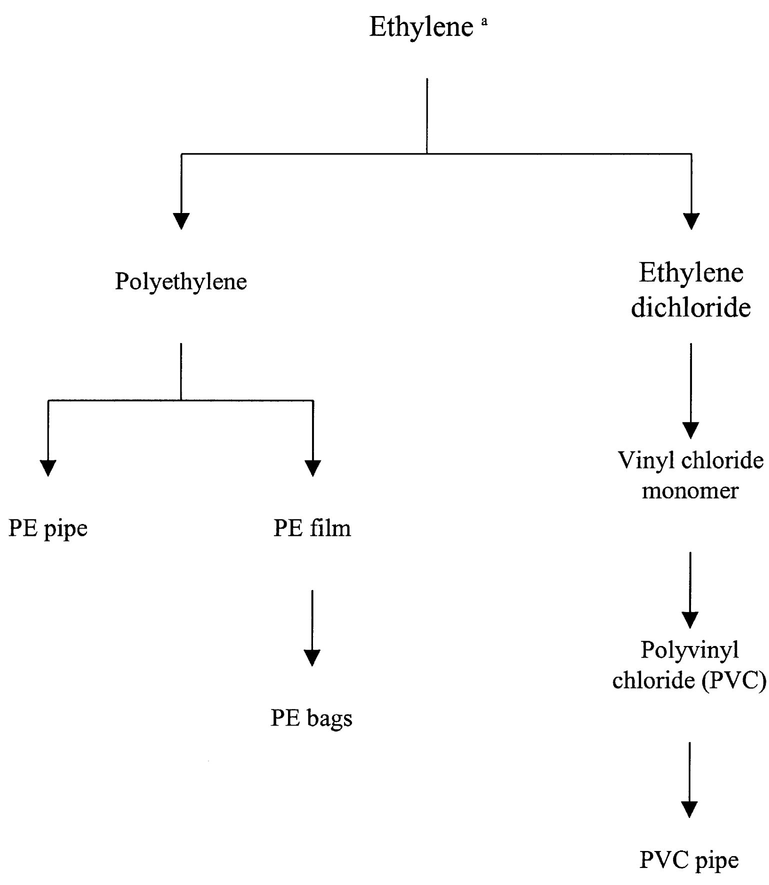
In summary, the literature documents that substantial contractual changes took place after the first oil price shock of 1973. The evidence indicates that in the face of high price uncertainty, contracts may not be optimal in governing transactions subject to asset

[9] Walker and Weber (1984, 1987) study the make-or-buy decision of automobile components. They find greater uncertainty about production volume increases the likelihood that a component is produced in-house. In the second paper, they find that the uncertainty only affects the make-or-buy decision when the market is thin. This interactive effect between uncertainty and asset specificity supports the transaction cost prediction. Several studies focus on the relations between downstream demand uncertainty and firms' decisions to forward integrate into sales or distribution. Anderson and Schmittlein (1984) and Anderson (1985) do not find demand uncertainty important in explaining forward integration into sales and distribution by electronic component manufacturers. The latter study does find that integration is positively affected by the interactive effect of asset specificity and demand uncertainty. John and Weitz (1988) find that downstream demand uncertainty positively affects the decision to maintain in-house sales forces in a sample of industrial manufacturers.

specificity. The transaction cost theory suggests a possibility for vertical integration been increasingly used in place of contracts to govern these transactions. This hypothesis will be examined with data from the petrochemical industry in the following analysis.

## 3. Overview of the industry

Petrochemical production proceeds in stages from original energy inputs to primary petrochemicals to intermediate products. The intermediate products are supplied to chemical processing industries for the manufacturing of detergents, fertilizers, pharmaceuticals, plastics, solvents, synthetic fibers, and synthetic rubbers. Fig. 1 provides an example of petrochemical production stages.




[a] Ethylene is derived from naphtha or natural gas. It is an input of a wider variety of petrochemicals than the ones illustrated here. The figure, meant to be illustrative, only shows two streams of ethylene derivatives.

Fig. 1. Example of petrochemical production stages.

### 3.1. Sources of asset specificity

The petrochemical industry has substantial temporal and site specificity. The temporal specificity is caused by technology and cost factors. Many processes require continuous flows of inputs to production plants. Disruptions of input flows cause lower production yields or even plant idling. Temporarily shutting down a plant is costly due to high fixed costs and substantial clean-up costs required before the plant can be put to on use again. The high costs associated with production interruption imply that non-performance in quantity, such as delaying delivery, can be an effective holdup strategy, even if the technology and the assets involved are quite common in nature.

Site specificity is also prevalent in the industry. Many petrochemical inputs are difficult to handle, transport, or store as inventories. This is particularly relevant for inputs that are of gaseous substances. They need to be stored in expensive, heavy, thick-walled tanks at very low temperatures and/or high pressures. For typical operating plants, the gaseous inputs can be stored for only a few hours or a few days before production. The inputs are transported over short distances by specialized trucks, trains, or barges equipped with storage tanks. These methods are not suitable for transportation over long distances, because the quality of the inputs deteriorates with time and travel distance. Transportation and storage concerns motivate suppliers and users of the gaseous petrochemical inputs to build plants in close proximity. As the plants are immobile, the users and the suppliers are locked into bilateral relationships that are subject to potential hold-up problems. The holdup problems related to storage and transportation costs have been found to affect the governance structures in the natural gas industry (Mulherin, 1986a). Likewise, site specificity in the petrochemical industry is expected to affect its firms' vertical integration decisions.[10]

### 3.2. Contracting problems after 1973

Supply contracts in the petrochemical industry typically have 1- to 3-year durations and are automatically renewed. Termination is permitted provided there is 3- to 6-month advanced notice. These contracts are intended to maintain long-term relationships between transactors while preserving flexibility for adaptation. Some contracts have very long terms, i.e., 10 to 20 years. These long-term contracts tend to be drawn for gaseous inputs produced and sold in remote locations.[11] Most contracts have price protection provisions allowing prices to be periodically adjusted within the contract duration. The

[10] The effects of site specificity on vertical integration are documented in several other studies. Joskow (1985) reports that while 85% of the coal used to generate electricity is supplied by the market mechanism, virtually all of the mine-mouth coal mines are owned by utilities. Spiller (1985) finds that combined excess stock returns of vertically merging firms upon their merger announcements are positively related to their geographic proximity.

[11] Dow Chemical has two 20-year contracts with Alberta Gas Ethylene agreeing to take substantial percentages of two ethylene plants' output (Dow Chemical 1996 Annual Report). Union Carbide has a 20-year ethylene contract to purchase part of the output of a Canadian ethylene plant (Union Carbide 1996 Annual Report).

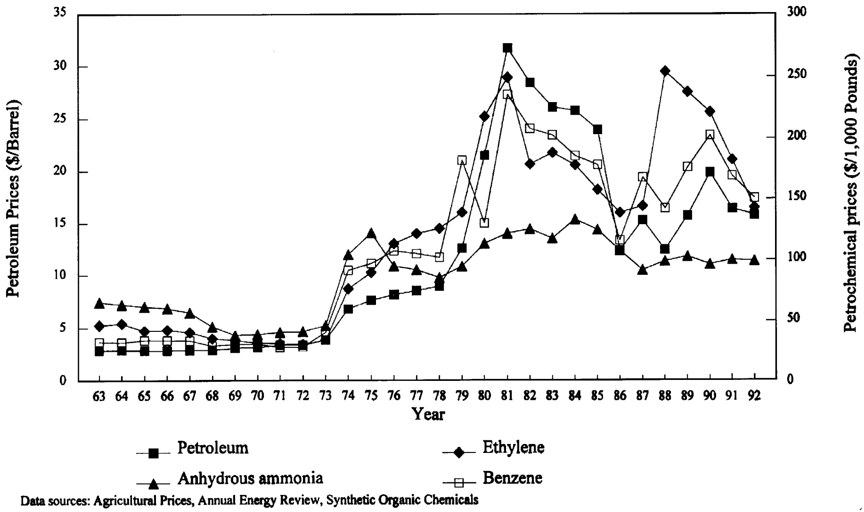



Fig. 2. Annual Petroleum and Selected Primary Petrochemicals Prices.

price adjustments are made by renegotiation or by predetermined formulas. In a typical price formula, the contract price is indexed to oil prices, wholesales prices, and other suppliers' cost factors. These price adjustment mechanisms are also observed in other industries such as natural gas (Mulherin, 1986a), petroleum coke (Goldberg and Erickson, 1987), and coal (Joskow, 1988).

Non-availability of historical data limits an investigation of how petrochemical contracts have evolved over time. However, public disclosures reveal that significant changes in contracting practices took place during the 1970s, especially shortly after the first oil price shock of 1973. It was reported that the frequency of price adjustments changed from quarterly to monthly.[12] Contract lengths became shorter for some petrochemical materials.[13] However, there was hardly a universal pattern of contractual changes across transactions, as some transactors responded to the oil price shocks by entering into long-term agreements.[14] What, then, has made 1973 a watershed of contractual changes? The clue is provided in the patterns of petrochemical input prices (Fig. 2). Before 1973, the input prices were generally stable with few fluctuations. After 1973, the levels and the volatility of the input prices increased dramatically. The sudden increase in price volatility created immense pressures for price adjustments in contracts.

[12] Chemical Marketing Reporter, 1974, 'Contract Terms Are Changing; Quarterly Importance Fading', 206, September 30, page 13.

[13] Chemical Marketing Reporter, 1973, 'Shorter Contracts and Curbs on Force Majeure Are Urged at EPCA Meeting in Venice', 204, October 8, page 4.

[14] Dow Chemical and Du Pont reported in their 1974 Annual Reports that they had entered into long-term arrangements to secure adequate quantities of petrochemical raw materials. In 1980, shortly after the second oil shock, Du Pont entered into a long-term arrangement with Shell Chemical to 'ensure' a supply of about one-third of its purchased domestic olefin feedstock needs over the following 10 years.

Prior to 1973, input price changes in the industry were infrequent.[15] The infrequent price changes in part reflected the stable price pattern during that period and in part reflected the transactors' unwillingness to haggle over prices.[16] Haggling increases the possibility of input disruptions that are costly to transactions subject to temporal specificity. To avoid haggling, the transactors would implicitly agree not to change prices often. That is, they would tolerate temporary small dispersions between the prices determined in their contracts and prices determined in other contracts or in spot markets.[17]

When the input prices were stable, the implicit agreements supported by the transactors' reputations were self-enforcing (Klein and Murphy, 1997; Baker et al., 1997). However, when the prices turned volatile after 1973, such contracts became difficult to maintain. During the period of price escalations, holdups by suppliers took the form of threats not to deliver the requested amounts unless buyers paid much higher prices than required by contract. Still other suppliers declared *force majeure*, due to their own procurement problems. In this case, the limited quantity of inputs would be rationed among existing customers.[18] There were strong incentives for suppliers to deviate from pro rata allocation. Suppliers were tempted to allocate more to customers paying higher prices while shorting others who paid lower prices. In his survey of the chemical industry's contracting practices in the 1970s, White (1982) reports that in the case of rationing, allocation was hardly on the pro-rata basis. He provides some explanation on why the deviation from pro rata allocation is possible. The conventional practice in the chemical industry was to specify a minimum and maximum quantity provision in contracts.[19] The intention of the suppliers was to urge the buyers to take as much as they could but not to insist that they take the minimum amount. As a result, the

[15] Carlton (1985) examines transaction prices of supply contracts during 1957–1966. He documents that the average duration between price changes for 658 chemical contracts was 12.8 months. This duration is long compared to the time between price changes for nonferrous metals (4.3), petroleum (5.9), plywood (4.7), and truck motors (5.4); and it is comparable to the durations for steel (13.0), cement (13.2), and glass (10.2). See also Mulherin (1986a), Goldberg and Erickson (1987), Joskow (1988), and Crocker and Masten (1988, 1991).

[16] The avoidance of frequent haggling became evident during my interviews with several petrochemical executives who were formally engaged in raw material purchasing during the 1970s.

[17] There has not been an organized spot exchange for petrochemical inputs. Some inputs are bought and sold for agreeable prices through spot networks where brokers or traders bring together buyers and sellers by telephone. Suppliers mainly use the spot markets to digest their excess supplies. Buyers access the spot markets either for their urgent needs or for low prices (Ching, 1986). The traders' roles in searching for information and facilitating transactions are similar to those of middlemen in the petroleum coke industry, as described by Goldberg and Erickson (1987). However, differences exist between the two. The coke middlemen are usually also coke producers. They enter contractual arrangements with other coke producers before reselling the coke to end users. On the other hand, traders of petrochemicals simply line up suppliers and buyers. They typically do not produce or consume the petrochemicals nor do they enter contracts with any parties.

[18] Rationing or allocating goods by quantity is not an uncommon practice in the industry. Suppliers occasionally use it when their products are on unexpected low supply due to a plant accident or a temporary surge in demand. See Barzel (1974) for an early discussion of rationing. See also Carlton (1991) for a more recent analysis.

[19] According to White (1982), the convention is deeply rooted in the industry, but the reason of it is unclear.

quantities specified in the contracts did not necessarily bear relationship with the quantities actually taken by the buyers historically. Most suppliers therefore allocated not by contract amounts but by historical take. The allocation by historical take provided the suppliers plenty of discretion, as it was hard for the buyers or the courts to monitor the historical take of individual buyers. In sum, the suppliers' incentives of deviating from pro rata allocation and the actual possibility of it created uncertainty in the buyers about being held up by their suppliers.

One potential solution to the ex post bargaining problems created by price uncertainty might have been the use of price indices. Unfortunately, price indices could not be relied on to indicate changes in petrochemical prices after 1973. Due to the high price volatility, the relations between the petrochemical prices and the price indices were unstable over time. The weakened price correlations thwarted index-based price adjustment mechanisms in supply contracts.[20] Price indices were therefore not sufficient to solve the contracting problems in the industry during the 1970s.

### *3.3. Organizational responses*

The contracting problems in the petrochemical industry during the 1970s created wide spread holdup problems in inter-firm contracts, which could not be easily alleviated by alternative contractual solutions. Were firms in the industry induced to integrate vertically into input production? Before an empirical investigation of this question, I describe how several organizations responded to the contracting problems.

#### *3.3.1. Du Pont*

Shortly after the first oil price shock, Du Pont, a leader of the petrochemical industry, experienced difficulties in procuring adequate raw materials for the production of numerous products. The raw material problem was caused primarily by the inability of certain suppliers to fulfill contract commitments. The problem was severe enough for Du Pont to embark on backward integration through a series of acquisitions. During 1975, Du Pont agreed to a joint venture with National Distillers and Chemical for the production and sale of synthetic gas and carbon monoxide to provide feedstock for production of methanol by Du Pont and acetic acid by National Distillers. Also, Du Pont and Atlantic Richfield entered into a joint venture for the production of petrochemical raw materials used in the manufacture of fibers, plastics, and elastomers. In 1976, Du Pont unsuccessfully attempted to acquire Shenandoah Oil, which was engaged in exploring for and producing oil and natural gas. In 1980, shortly after the second oil price shock, Du Pont entered into a joint natural gas exploration program with Conoco, Du Pont eventually acquired the entire natural resource concern in 1981.

#### *3.3.2. Hercules*

By 1975, Du Pont was the single largest consumer of Hercules' product, dimethyl terephthalate (DMT), which is used to produce polyester. Hercules, in response to Du

[20] See Goldberg (1985), Goldberg and Erickson (1987), and Joskow (1988).

Pont's earlier request to increase the supply, doubled its DMT capacity. Shortly after the first oil price shock, Du Pont unexpectedly announced its decision to become a self-sufficient producer of polyester intermediates. The reversal came as an enormous surprise to Hercules. Construction of a new production plant was halted immediately, resulting in a write-off of about $14 million.[21] The reaction of Hercules to Du Pont's contractual breach was to exit gradually from the DMT business.

### *3.3.3. PPG*

PPG is a leading producer of glass and coating materials. In the late 1960s, the company decided to begin producing primary petrochemicals. It entered a 50–50 joint venture with Commonwealth Oil Refining (CORCO) to construct, at that time, one of the world's largest olefin plants at Penuelas, Puerto Rico. The plant made primary petrochemicals from petroleum feedstock purchased from CORCO. PPG also built a wholly owned complex at Guayanilla, Puerto Rico, which used the ethylene from the olefin plant to produce a variety of petrochemical intermediates. PPG's total investment in Puerto Rico was $150 million.

The Puerto Rican operations began in 1971. In 1973, shortly after the first oil shock, "CORCO experienced difficulty in supplying sufficient feedstock to keep the olefin plant operating and refused to supply any feedstock except at substantially higher prices than had been contracted for".[22] CORCO and PPG filed suit against each other; the dispute was settled in 1975. However, CORCO later filed a petition for bankruptcy protection in 1978, and it asked the Court for authority to reject the PPG–CORCO joint venture and integration agreements.[23] The Court granted CORCO's request. PPG took over the joint venture and was later forced to shut down the olefin plant and its wholly owned downstream operations in Puerto Rico. The Puerto Rican operations contributed to operating losses of more than $140 million between 1971 and 1978. PPG eventually abandoned its involvement in the primary petrochemical sector.

The above anecdotal evidence indicates that contracting problems in the 1970s were sufficiently severe to affect firms' organizational choices. In particular, the Du Pont's response to its contracting problems suggests that vertical integration could be optimal for some firms in the face of high price uncertainty. I investigate this hypothesis in the following empirical analysis.

[21] Hercules' CEO, in an interview with Dyer and Sicilia (1990, p 390), recalled that "Du Pont arrived at this decision after one of its suppliers in another product line suddenly raised prices. Because Du Pont relied heavily on the supplier, it had little choice but to pay. To avoid what they regarded as extortion — or the threat of it — Du Pont's top executives resolved that the company would no longer tolerate dependence upon any single supplier...We (Hercules) talked seriously about suing the Du Pont company for leading us on in this manner but decided there was no profit in attempting to sue one of our most important customers. We already had a penalty clause in our contract, and indeed, Du Pont paid a modest penalty for materials it did not take".

[22] PPG, 1974 Annual Report.

[23] PPG, 1978 Special Letter to Shareholders.

## 4. Empirical analysis

In this section, I report on a large-sample empirical investigation into the questions of whether and under what conditions firms embark upon vertical integration in the face of price uncertainty. In the process, the transaction cost hypotheses as well as several rival hypotheses will be tested.

### *4.1. Data sample*

The sampling years include 1972, 1982, and 1992. The three samples facilitate the comparison of vertical integration before, during, and after the period of the oil price shocks. I primarily employ two data sources identified by Lieberman (1991): *Directory of Chemical Producers* (SRI International, various years) and *Synthetic Organic Chemicals* (US International Trade Commission, various years). The former source provides exhaustive information on annual plant capacity, location, and ownership for approximately 200 chemical products in the domestic US market. The latter contains annual production, sales, and unit values of a wide variety of chemicals. Additional data including annual prices and production quantities of ammonium products are secured from the Agricultural Prices (US Department of Agriculture, various years) and Current Business Statistics, (US Department of Commerce, various years) respectively.

From these data sources, a list of products and their primary inputs is prepared. For a product to be included, the following criteria must be met to enable the construction of empirical measures. First, the product must have an identifiable primary input and not be a by-product. Second, domestic plant capacity and ownership data for the product and its primary input must be available in the three sampling years. Lastly, annual prices of the primary input must be available between 1963 and 1992. The sampling criteria result in a list of 49 products. Table 1 presents the sample products, their producers in number, their primary inputs, and input substances. As reported, the 49 products are each derived from one of 24 primary inputs. There are totally 490, 409 and 347 product-firms in 1972, 1982, and 1992, respectively. The number of producers of a given product ranges from several to more than 40. The average number of producers across the products is 10, 8, and 7 in the three samples, respectively. The decreased average number of producers over time reflects the trend of producers exiting from the industry since the 1970s.

Table 2 presents a list of the top 50 producers ranked by the total number of observations for each producer over the three years. The observations are diversely distributed across the producers, as no single producer accounts for more than 5% of the total observations. For the three sampling years as a whole, the top 50 producers account for 64% of the observations. Among the top 50 producers, 23 are chemical companies, 19 are oil-and-gas companies, and the remaining 8 are diversified companies with significant businesses outside the chemical and the oil-and-gas industries.

### *4.2. Measurement*

#### *4.2.1. Vertical integration*

Vertical integration is measured by the input self-sufficiency ratio (ISR): a firm's in-house input capacity divided by the required input capacity to support completely the

Table 1
Sample petrochemical products, their producers in number, their primary inputs, and input substances

| No. | Product | Number of Producers | | | Primary input | Input is gaseous |
|---|---|---|---|---|---|---|
| | | 1972 | 1982 | 1992 | | |
| 1 | ABS resins | 7 | 3 | 3 | Styrene | No |
| 2 | Acetic acid | 6 | 5 | 4 | Methanol | No |
| 3 | Acetone | 4 | 4 | 1 | Isopropyl alcohol | No |
| 4 | Acrylic acid | 1 | 4 | 4 | Propylene | Yes |
| 5 | Acrylonitrile | 4 | 4 | 5 | Propylene | Yes |
| 6 | Adipic acid | 5 | 2 | 2 | Cyclohexanone | No |
| 7 | Ammonium nitrate | 38 | 32 | 25 | Ammonia | Yes |
| 8 | Ammonium phosphate | 28 | 24 | 14 | Ammonia | Yes |
| 9 | Ammonium sulfate | 8 | 6 | 5 | Ammonia | Yes |
| 10 | Benzoid acid | 5 | 3 | 2 | Toluene | No |
| 11 | Benzyl chloride | 4 | 3 | 2 | Toluene | No |
| 12 | Bisphenol A | 4 | 5 | 4 | Phenol | No |
| 13 | Caprolactam | 2 | 2 | 2 | Cyclohexane | No |
| 14 | Cumene | 12 | 12 | 10 | Benzene | No |
| 15 | Cyclohexane | 9 | 8 | 4 | Benzene | No |
| 16 | Cyclohexanone | 8 | 4 | 4 | Cyclohexane | No |
| 17 | Dimethylterephthalate | 5 | 3 | 3 | *p*-Xylene | No |
| 18 | Ethanolamines | 5 | 4 | 4 | Ethyl oxide | Yes |
| 19 | Ethyl acetate | 5 | 4 | 2 | Ethyl alcohol | No |
| 20 | Ethyl chloride | 6 | 4 | 1 | Ethylene | Yes |
| 21 | Ethylbenzene | 14 | 12 | 12 | Ethylene | Yes |
| 22 | Ethylene dichloride | 12 | 12 | 11 | Ethylene | Yes |
| 23 | Ethylene glycol | 13 | 11 | 10 | Ethylene | Yes |
| 24 | Ethylene oxide | 13 | 12 | 10 | Ethylene | Yes |
| 25 | Formaldehyde | 19 | 13 | 16 | Methanol | No |
| 26 | Fumaric acid | 5 | 4 | 3 | Maleic anhydride | No |
| 27 | Hexamethylene Tetramine, TECH | 7 | 6 | 2 | Formaldehyde | No |
| 28 | Isopropyl alcohol | 4 | 4 | 3 | Propylene | Yes |
| 29 | Maleic anhydride | 6 | 2 | 4 | Benzene | No |
| 30 | Methyl Isobutyl ketone | 4 | 4 | 3 | Acetone | No |
| 31 | Methyl mecrylate | 3 | 3 | 3 | Acetone | No |
| 32 | *n*-Butyl acetate | 4 | 3 | 3 | *n*-Butyl alcohol | No |
| 33 | *n*-Butyl alcohol | 7 | 7 | 5 | Propylene | Yes |
| 34 | Nitric acid | 46 | 38 | 34 | Ammonia | Yes |
| 35 | Nitrobenzene | 7 | 5 | 5 | Benzene | No |
| 36 | Pentaerythritol, MONO | 5 | 4 | 3 | Formaldehyde | No |
| 37 | Phthalic anhydride | 8 | 5 | 4 | *o*-Xylene | No |
| 38 | Polyethylene-HD | 13 | 13 | 10 | Ethylene | Yes |
| 39 | Polyethylene-LD | 14 | 12 | 10 | Ethylene | Yes |
| 40 | Polypropylene | 9 | 11 | 16 | Propylene | Yes |
| 41 | Polystyrene | 18 | 16 | 16 | Styrene | No |
| 42 | Polyvinyl alcohol | 4 | 3 | 3 | Vinyl acetate | No |
| 43 | Polyvinyl chloride resins | 21 | 15 | 13 | Vinyl chloride | No |
| 44 | Propylene oxide | 6 | 1 | 2 | propylene | Yes |

Table 1 (*continued*)

| No. | Product | Number of Producers | | | Primary input | Input is gaseous |
|---|---|---|---|---|---|---|
| | | 1972 | 1982 | 1992 | | |
| 45 | SBR rubber | 10 | 7 | 4 | 1,3-Butadiene | Yes |
| 46 | Styrene | 10 | 9 | 8 | Ethylbenzene | Yes |
| 47 | Urea | 31 | 28 | 19 | Ammonia | Yes |
| 48 | Vinyl acetate | 3 | 4 | 4 | Ethylene | Yes |
| 49 | Vinyl chloride | 8 | 9 | 10 | Ethylene dichloride | No |
| Total number of producers | 490 | 409 | 347 | | | |
| Average number of producers | 10.00 | 8.35 | 7.08 | | | |

manufacturing of its product. The denominator of ISR, the required input capacity, is estimated from multiplying the product capacity with the input–output conversion ratio — the quantity of the input required for producing a one-unit quantity of the output. When the firm uses the input to produce multiple products, its in-house input capacity is prorated by the individual products' input requirements. By construction, ISR is bounded below by zero but not bounded above.

Panel A of Table 3 reports summary statistics of ISR. The mean ISR is 2.00, 1.44, and 1.30 in the 1972, 1982, and 1992 samples, respectively. The values suggest that the average firm is more than self sufficient in its input requirement. However, substantial differences in the value of ISR exist across products and firms, as indicated by the large standard errors, 5.18, 2.89, and 2.44, in the three respective years. The medians of ISR are 0.99, 0.82, and 0.77, substantially smaller than the mean statistics. The differences suggest that extreme values cause the reported large mean statistics. The existence of the extreme values is also indicated by the maximum statistics, 70.83, 41.78, and 21.13, in the three respective years. Both the mean and median statistics display a decreasing pattern over time, suggesting that the overall degree of input self-sufficiency has been declining.

Panel B of Table 3 reports the sample distribution across different levels of input self-sufficiency. There exists a wide dispersion of organizational choices across the firms and product sectors. Some producers rely solely on external markets for inputs. In the three respective years, 30%, 31%, and 40% of the sample firms do not produce any input in-house. Some producers are partially integrated: 19%, 24%, and 23% of the firms in the three respective years produce some but less than sufficient inputs in-house. There are also fully integrated producers: 50%, 44%, and 35% of the sample firms are fully or more than fully self-sufficient in their input requirements.

#### *4.2.2. Independent variables*

In Section 2, the transaction cost theory makes predictions regarding how vertical integration is affected by price uncertainty and asset specificity. To test these predictions, several proxy variables are selected based on the industry characteristics discussed

Table 2
Top-50 petrochemical producers

| Rank[a] | Firm[b] | Number of product-firms | | | | Cum%[c] | Type[d] |
|---|---|---|---|---|---|---|---|
| | | 1972 | 1982 | 1992 | Total | | |
| 1 | Union Carbide | 24 | 16 | 13 | 53 | 4.25 | Chemical |
| 2 | Monsanto | 22 | 19 | 10 | 51 | 8.35 | Chemical |
| 3 | Du Pont | 14 | 19 | 11 | 44 | 11.88 | Chemical |
| 4 | Dow Chemical | 16 | 14 | 13 | 43 | 15.33 | Chemical |
| 5 | Royal Dutch/Shell (Netherlands/UK) | 13 | 12 | 8 | 33 | 17.98 | Oil and gas |
| 6 | Eastman Kodak | 11 | 10 | 10 | 31 | 20.47 | Diversified |
| 7 | Celanese | 14 | 10 | 0 | 24 | 22.39 | Chemical |
| 8 | BASF (Germany) | 5 | 9 | 8 | 22 | 24.16 | Chemical |
| 9 | AMOCO (Standard Oil of IN) | 7 | 6 | 6 | 19 | 25.68 | Oil and gas |
| 10 | Exxon (Standard Oil of NJ) | 7 | 7 | 5 | 19 | 27.21 | Oil and gas |
| 11 | Phillips Petroleum | 8 | 7 | 3 | 18 | 28.65 | Oil and gas |
| 12 | Allied Chemical | 13 | 4 | 0 | 17 | 30.02 | Chemical |
| 13 | Chevron (Standard Oil of CA) | 5 | 3 | 9 | 17 | 31.38 | Oil and gas |
| 14 | Gulf Oil | 9 | 8 | 0 | 17 | 32.74 | Oil and gas |
| 15 | Hercules | 9 | 5 | 3 | 17 | 34.11 | Chemical |
| 16 | Occidental Petroleum | 6 | 3 | 8 | 17 | 35.47 | Oil and gas |
| 17 | USX (US Steel) | 7 | 10 | 0 | 17 | 36.84 | Diversified |
| 18 | Borden | 7 | 7 | 2 | 16 | 38.12 | Diversified |
| 19 | Air Products and Chemicals | 5 | 6 | 4 | 15 | 39.33 | Chemical |
| 20 | Olin | 9 | 5 | 1 | 15 | 40.53 | Chemical |
| 21 | Atlantic Richfield | 2 | 7 | 4 | 13 | 41.57 | Oil and gas |
| 22 | PPG | 5 | 5 | 3 | 13 | 42.62 | Diversified |
| 23 | BF Goodrich | 5 | 4 | 3 | 12 | 43.58 | Diversified |
| 24 | CF Industries | 4 | 4 | 4 | 12 | 44.54 | Chemical |
| 25 | Mississippi Chemical | 4 | 4 | 4 | 12 | 45.51 | Chemical |
| 26 | Quantum Chemical (Nat'l Distillers and Chem.) | 2 | 3 | 7 | 12 | 46.47 | Chemical |
| 27 | Texaco | 2 | 5 | 5 | 12 | 47.43 | Oil and gas |
| 28 | American Cyanamid | 6 | 5 | 0 | 11 | 48.31 | Chemical |
| 29 | Hoechst Celanese (Germany) | 0 | 0 | 11 | 11 | 49.20 | Chemical |
| 30 | J.R. Simplot | 2 | 5 | 4 | 11 | 50.08 | Chemical |
| 31 | ICI (UK) | 4 | 4 | 2 | 10 | 50.88 | Chemical |
| 32 | Reichhold Chemical | 6 | 4 | 0 | 10 | 51.69 | Chemical |
| 33 | Coastal Corp | 1 | 4 | 4 | 9 | 52.41 | Oil and gas |
| 34 | El Paso Natural Gas | 5 | 4 | 0 | 9 | 53.13 | Oil and gas |
| 35 | Ethyl | 4 | 5 | 0 | 9 | 53.85 | Chemical |
| 36 | Farmland Industries | 1 | 4 | 4 | 9 | 54.57 | Chemical |
| 37 | Getty Oil | 4 | 5 | 0 | 9 | 55.30 | Oil and gas |
| 38 | Mobil Oil | 4 | 3 | 2 | 9 | 56.02 | Oil and gas |
| 39 | Tenneco | 8 | 1 | 0 | 9 | 56.74 | Diversified |
| 40 | Terra Chemical International | 3 | 3 | 3 | 9 | 57.46 | Chemical |
| 41 | Union Oil of CA | 5 | 4 | 0 | 9 | 58.19 | Oil and gas |
| 42 | W.R. Grace | 4 | 5 | 0 | 9 | 58.91 | Diversified |
| 43 | Fina (American Petrofina, Belgium) | 3 | 2 | 3 | 8 | 59.55 | Oil and gas |

Table 2 (*continued*)

| Rank[a] | Firm[b] | Number of product-firms | | | | Cum%[c] | Type[d] |
|---|---|---|---|---|---|---|---|
| | | 1972 | 1982 | 1992 | Total | | |
| 44 | Cominco American | 2 | 3 | 3 | 8 | 60.19 | Chemical |
| 45 | Standard Oil of OH | 4 | 4 | 0 | 8 | 60.83 | Oil and gas |
| 46 | Williams | 4 | 4 | 0 | 8 | 61.48 | Oil and gas |
| 47 | Georgia-Pacific | 1 | 5 | 1 | 7 | 62.04 | Diversified |
| 48 | Koch | 3 | 2 | 2 | 7 | 62.60 | Oil and gas |
| 49 | Rohm and Hass | 3 | 2 | 2 | 7 | 63.16 | Chemical |
| 50 | Sun Oil | 4 | 1 | 2 | 7 | 63.72 | Oil and gas |
| Sub-total | 316 | 291 | 187 | 794 | 63.72 | | |
| All others | 174 | 118 | 160 | 452 | 36.28 | | |
| Total | 490 | 409 | 347 | 1246 | 100.00 | | |

[a] The producers are ranked by the total number of observations (product-firms) in the three sampling years.
[b] Prior names and foreign ownership are indicated in parentheses.
[c] The numbers indicate cumulative percentages of product-firms over the full sample.
[d] The producers are each classified into the chemical, oil-and-gas, or diversified type according to their main business involvement.

in Section 3. I describe the proxies and their predicted relations with vertical integration as follows.

Table 3
Input self-sufficiency ratios[a] (ISR) of petrochemical firms

| | 1972 | 1982 | 1992 |
|---|---|---|---|
| *Panel A: Summary statistics* | | | |
| Mean | 2.00 | 1.44 | 1.30 |
| Standard error | 5.18 | 2.89 | 2.44 |
| Median | 0.99 | 0.82 | 0.77 |
| Maximum | 70.83 | 41.78 | 21.13 |
| Minimum | 0.00 | 0.00 | 0.00 |
| *Panel B: Distribution of firms by levels of input self-sufficiency* | | | |
| ISR = 0 | 151 (30.8%) | 128 (31.3%) | 141 (40.6%) |
| 0 < ISR < 0.5 | 26 (5.3%) | 37 (9.0%) | 9 (2.6%) |
| 0.5 < = ISR < 1 | 68 (13.9%) | 61 (15.0%) | 73 (21.1%) |
| ISR > = 1 | 245 (50.0%) | 183 (44.7%) | 124 (35.7%) |
| Total product-firms | 490 | 409 | 347 |

[a] The input self-sufficiency ratio (ISR) is the firm's in-house input capacity divided by the required input capacity to fully support the manufacturing of its product. The denominator of the ISR, the required input capacity, is estimated from multiplying the product capacity with the input-output conversion ratio — the quantity of the input required for producing a one-unit quantity of the product. When the firm uses the input to produce more than one product, its in-house input capacity is prorated by the individual products' input requirements.

The first variable is input price uncertainty (*Pu*), measured as the standard deviation of residuals from the following de-trending regression:

$$\log(P_{it}) = a_i + b_i t + u_{it},$$

where $P_{it}$ is the average price of the $i$th input in year $t$. The regression is run for each of the inputs and each decade ending in 1972, 1982, and 1992, using annual prices of the 10 prior-and-inclusive years. The theory predicts a positive relation between *Pu* and vertical integration, particularly during the 1970s.

The second variable is asset specificity. To capture asset specifity, I use a dummy variable, *Gas*, as in Lieberman (1991). *Gas* equals one if the input in question is a gas, or else it equals zero. Many petrochemical processes involve gaseous inputs. As reported earlier in Table 1, 6 of the 24 inputs in the sample are gaseous. The same table shows that 22 of the 49 products in the sample require gaseous inputs. Gaseous inputs are associated with greater temporal and site specificity than non-gaseous inputs. I expect a positive relation between *Gas* and vertical integration.

The transaction cost theory emphasizes the interactive effects of uncertainty and asset specificity. That is, the larger the asset specificity, the greater the organizational response to uncertainty. It can therefore be expected that, in the face of high price uncertainty, gaseous input users will maintain a higher degree of input self-sufficiency than will users of non-gaseous inputs. This hypothesis will be tested in regression analysis where *Gas* interacts with *Pu*. A significant positive estimated coefficient of the interaction term will be consistent with the hypothesis.

Several control variables are considered in the analysis. The first control variable is the producer's scale (*Scale*) measured as a producer's total capacity divided (normalized) by the average capacity of all producers of the same product. The producer's scale can affect vertical integration through a reputation effect or a production cost effect. The cited studies of Klein and Murphy (1997) and Baker et al. (1997) predict a positive relation between a firm's degree of vertical integration and the size of its reputation capital. Assuming a firm with a larger production scale also has more reputation capital, one expects a positive relation between *Scale* and the extent that the firm integrates into the input stage. Alternatively, the producer's scale can affect input production costs. Riordan and Williamson (1985) predict that vertical integration is positively related to firm size. They reason that as the size of a firm increases, its input requirement increases, and hence the production cost of in-house production of the input becomes lower through the scale effect. Using *Scale* as a proxy for firm size, one expects a positive relation between *Scale* and the extent of the firm's input self-sufficiency. Both of the reputation and the production cost effects reach the same prediction: a positive relation between *Scale* and vertical integration.

Another control factor is capacity balance. Balancing capacity between production stages has been shown to be important in the aluminum industry. Stuckey (1983) reports that integrated firms on average have balanced capacity across the mining, smelting, and fabricating stages of the industry. He argues that, in so doing, the firms are able to circumvent thin intermediate markets. Consider the following example that is typical in the petrochemical industry. The efficient scale of a downstream plant is small while the efficient scale of its corresponding upstream (input) plant is large. A firm producing at the efficient scale will face a capacity-balancing problem when it integrates into the input stage. It will have to produce either the input at a less-than-efficient scale to maintain capacity balance or build an efficient input plant and sell excess input to the market. Both of the options may be overly costly and hence discourage the firm's vertical integration. I construct a proxy, *Bcap*, to capture the capacity balance effect. For a given product, *Bcap* is the average capacity of input plants divided by the average capacity of product plants. One expects a negative relation between *Bcap* and input self-sufficiency.

Table 4 provides a summary of the independent variables, their predicted relations with vertical integration, and their empirical measures. As indicated, the transaction cost theory predicts that the input self-sufficiency in the industry increases with the use of gaseous inputs, the degree of input price variability, and the joint effect of the two. The literature also predicts that the input self-sufficiency is positively affected by producer's scale and the size of the input plant relative to that of the product plant.

### *4.2.3. Basic statistics*

Table 5 presents mean statistics of the independent variables. The table also compares means of the variables between producers that own input plants and those that do not. Of the 490, 409, and 347 product-firms, 339, 281, and 206 owned at least one input plant in 1972, 1982, and 1992, respectively. Several observations are worth noting from the table. First, the highest input price uncertainty occurred in the decade of the oil price shocks, followed by the more recent decade, then by the decade prior to 1973. Consistent with the prediction, the firms that owned input plants in 1982 on average experienced larger input price uncertainty in the 1970s than the firms without input plant ownership; the difference is statistically significant at the 1% level. But the difference is not significant in the 1972 and the 1992 samples. Second, the majority of the firms in the sample use gaseous inputs: 58%, 61%, and 59% of the firms in the three respective samples. Moreover, firms are more likely to own input plants if their inputs are gaseous,

Table 4
The independent variables, their predicted relations with vertical integration, and their empirical measures

| Variable | Predicted relation with vertical integration | Empirical measure |
|---|---|---|
| Input price uncertainty (*Pu*) | Positive | Standard deviation of residuals from the input price de-trending regression[a] |
| Asset specificity (*Gas*) | Positive | Dummy variable equal to one if the input is gaseous, or zero if otherwise |
| $Pu * Gas$ | Positive | Product of the input price uncertainty and the asset specificity measures |
| Producer's scale (*Scale*) | Positive | Producer's capacity normalized by the average capacity of all producers |
| Capacity balance (*Bcap*) | Negative | Average input plant capacity divided by average product plant capacity |

[a] The de-trending regression is $\log(P_{it}) = a_i + b_i t + u_{it}$, where $P_{it}$ is the average price of the $i$th input in year $t$. The regression is run for each of the inputs and each decade ending in 1972, 1982, and 1992, using annual prices of the 10 prior-and-inclusive years.

Table 5
Mean statistics of the independent variables and comparison of the mean variables between producers' that own input plants and others that do not[a]

| Variable[b] | Year | All producers | Producers with input plant ownership | Producers without input plant ownership | *T*-statistic for diffirence in means |
|---|---|---|---|---|---|
| *Pu*, | 1972 | 0.0828 | 0.0812 | 0.0864 | −0.81 |
| input price uncertainty | 1982 | 0.2518 | 0.2554 | 0.2439 | 2.97*** |
| | 1992 | 0.1735 | 0.1746 | 0.1718 | 0.33 |
| *Gas*, | 1972 | 0.58 | 0.65 | 0.41 | 5.17*** |
| asset specificity | 1982 | 0.61 | 0.67 | 0.47 | 3.73*** |
| | 1992 | 0.59 | 0.65 | 0.51 | 2.46*** |
| *Scale*, | 1972 | 1.42 | 1.56 | 1.08 | 4.47*** |
| producer's scale | 1982 | 1.52 | 1.71 | 1.12 | 4.64*** |
| | 1992 | 1.48 | 1.63 | 1.26 | 2.53*** |
| *Bcap*, | 1972 | 4.75 | 4.55 | 5.18 | −1.3 |
| capacity balance | 1982 | 4.15 | 3.96 | 4.56 | −1.43 |
| | 1992 | 4.41 | 3.71 | 5.42 | −3.53*** |

*Significant at the 0.10 level; **Significant at the 0.05 level.
***Significant at the 0.01 level.
[a]Of the 490, 409, and 347 observations (product-firms), 339, 281, and 206 owned at least one input plant in 1972, 1982, and 1992, respectively.
[b]*Pu* is the standard deviation of residuals from the de-trending regression: $\log(P_{it}) = a_i + b_i t + u_{it}$, where $P_{it}$ is the price of the $i$th input in year $t$. The regression is run for each of the inputs and each decade ending in 1972, 1982, and 1992, using annual prices of the 10 prior-and-inclusive years. *Gas* is a dummy variable equal to one if the input is gaseous, or zero if not. *Scale* is the producer's capacity normalized by the average capacity of all producers. *Bcap* is the average capacity of input plants divided by the average capacity of product plants.

consistent with the predicted effect of asset specificity. In 1982, 67% of the firms owning input plants used gaseous inputs, whereas only 47% of the firms not owning input plants used gaseous inputs. The difference is statistically significant at the 1% level. Similar differences are also registered for the 1972 and the 1992 samples. Third, the average value of *Scale* is significantly greater for the firms with input plant ownership than the firms without input plant ownership in each of the three sampling years. The evidence is consistent with the reputation and the production cost effects. Fourth, as the mean statistics of *Bcap* indicate, the average capacity of petrochemical input plants is more than four times larger than the average capacity of downstream product plants. Consistent with the capacity balance effect, *Bcap* is generally smaller for product-firms owning input plants than other firms not owning input plants, though the difference is significant only in the 1992 sample.

In summary, the results of the univariate comparisons in Table 5 are generally consistent with the predicted effects of price uncertainty and asset specificity. The results also suggest that the reputation, production cost, and capacity balance effects are relevant to vertical integration in the industry and should be controlled in regression analysis.

### 4.3. Regression analysis

This section reports on multivariate regression analysis to examine the transaction cost hypotheses. I examine individual effects of price uncertainty and asset specificity, joint effects of the two, and effects of industry agglomeration.

#### 4.3.1. Individual effects

For each of the three sampling years, separate Tobit regressions are performed to determine the effects of input price uncertainty, asset specificity, and the control variables on the input self-sufficiency of the producers. To mitigate the bias resulting from some extraordinarily large values of ISR, the dependent variable is re-defined as $VI = \log(\text{ISR} * 100)$, where each of the zero-value ISR*s* is replaced by 1 before taking the natural logarithm.

Equations (1), (2), and (4) of Table 6 report the coefficients estimated separately from the 1972, the 1982, and the 1992 samples. An overview across the equations reveals several results. First, the estimated coefficients of *Gas* are all positive and significant at the 1% level. Given that gaseous inputs are associated with higher degrees of asset specificity than non-gaseous inputs, the evidence is consistent with the transaction cost

Table 6
Tobit regressions of vertical integration on input price uncertainty, asset specificity, and control variables[a]

| Independent variable[b] | 1972 | 1982 | | 1992 |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| *Intercept* | 1.77*** | −1.63 | −3.90*** | 1.35* |
| | (4.31) | (−1.33) | (−3.93) | −1.63 |
| $VI_{72}$ | | | 1.05*** | |
| | | | (15.21) | |
| *Gas* | 1.39*** | 1.54*** | 0.49* | 1.22*** |
| | (4.34) | (4.40) | (1.81) | (2.54) |
| *Pu* | −1.64 | 12.66*** | 10.03*** | 0.66 |
| | (−0.64) | (2.77) | −2.85 | (0.13) |
| *Scale* | 0.37*** | 0.44*** | 0.08 | 0.45*** |
| | (3.36) | (4.00) | (1.00) | (2.81) |
| *Bcap* | −0.01 | −1.00** | −0.04 | −0.22*** |
| | (−0.12) | (−2.22) | (−1.14) | (−4.40) |
| Log likelihood | −1042 | −848 | −490 | −688 |
| Observations | 490 | 409 | 285 | 347 |

Asymptotic *t*-statistics are in parentheses.

* Significant at the 0.10 level.

** Significant at the 0.05 level.

*** Significant at the 0.01 level.

[a] The dependent variable is $VI = \log(\text{ISR} * 100)$, where ISR is the input self-sufficiency ratio. If ISR = 0, it is set to 1 before taking log.

[b] $VI_{72}$ is *VI* measured in 1972. *Gas* is a dummy variable equal to one if the input is gaseous, or zero if not. *Pu* is the standard error of residuals from the de-trending regression: $\log(P_{it}) = a_i + b_i t + u_{it}$, where $P_{it}$ is the average price of the $i$th input in year $t$. The regression is run for each of the inputs and each decade ending in 1972, 1982 and 1992, using annual prices of the 10 prior-and-inclusive years. *Scale* is the produce's capacity normalized by the average capacity of all producers. *Bcap* is the average capacity of input plants divided by the average capacity of product plants.

view that vertical integration increases with asset specificity. Second, the estimated coefficient of *Pu* is positive and statistically significant at the 1% level in the 1982 sample but not significant in the 1972 and 1992 samples. The evidence is consistent with the view that the holdup problems unique to the high price uncertainty in the 1970s are not mitigated by alternative contractual mechanisms, forcing firms to increase their degrees of vertical integration. Third, vertical integration increases with *Scale*, as the estimated coefficients are positive and significant at the 1% level across the equations. *Scale* used as a proxy for the size of the producer's reputation capital provides evidence for the argument that vertical integration facilitates self-enforcement by giving ownership rights to the more reputable parties in transactions (Klein and Murphy, 1997; Baker et al., 1997). Alternatively, using *Scale* as a proxy for firm size, the evidence is consistent with the argument that large firms face smaller production cost disadvantage relative to markets when they integrate into input stages (Riordan and Williamson, 1985). Lastly, the estimated coefficients of *Bcap* are generally negative and are statistically significant in the 1982 and 1992 samples. The evidence is consistent with the capacity balance effect of Stuckey (1983).

As a test of robustness, a partial adjustment model is performed on 285 product firms that survived through the decade between 1973 and 1982. The dependent variable is the 1982 *VI*. The model includes *VI* measured in 1972 as one additional independent variable. The equation used for (3) in Table 6 reports the estimated coefficients. As one would expect, the estimated coefficient of the lagged *VI* is positive and highly significant. The effect of *Pu* remains positive and significant at the 1% level. The coefficients of *Gas*, *Scale, and Bcap* maintain their previous signs but their explanatory power becomes weaker.

One condition to contemplate is the high inflation during the decade after 1973, particularly in 1982. Might the inflation cause a spurious relation between the price uncertainty and the vertical integration measures, as reported in Table 6 and earlier in Table 5? Two reasons suggest that it does not. First, price trends have been removed from the price uncertainty measure through the de-trending regressions. Second, the vertical integration measure is constructed from the 1982 plant capacity data. If the 1982 inflation had affected vertical integration, any effects would show up in the capacity data of later years because altering plant capacity typically requires a lead time of 1 to 2 years.

In summary, the results from the multiple regressions in Table 6 are generally consistent with the predictions of the transaction cost theory. The firms' vertical integration into input production is positively affected by asset specificity and the price uncertainty provoked by the oil price shocks. The evidence from the control variables indicates that the reputation, production cost, and capacity balance factors systematically affect the firms' extents of input self-sufficiency.

### 4.3.2. Joint effects

It has been predicted that the impact of input price uncertainty on vertical integration increases with asset specificity. To examine this hypothesis, the regression models of Table 6 are amended with an interaction term, $Pu * Gas$, and then re-estimated. Table 7 presents the results of this analysis. Equations (1), (2), and (4) in Table 7 report the

Table 7
Tobit regressions of the interactive effects of input price uncertainty and asset specificity on vertical integration[a]

| Independent variable[b] | 1972 | 1982 | | 1992 |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| *Intercept* | 2.00*** | −0.03 | −2.95*** | 1.35 |
| | (4.65) | (−0.02) | (−2.63) | (1.28) |
| $VI_{72}$ | | | 1.04*** | |
| | | | (15.07) | |
| *Gas* | 0.17 | −5.49* | −3.04 | 1.21 |
| | (0.24) | (−1.90) | (−1.42) | (0.95) |
| *Pu* | −3.40 | 6.7 | 6.60* | 0.64 |
| | (−1.26) | (1.30) | (1.64) | (0.13) |
| *Pu* ∗ *Gas* | 16.01** | 28.10*** | 14.18* | 0.05 |
| | (1.96) | (2.45) | (1.67) | (0.00) |
| *Scale* | 0.36*** | 0.45*** | 0.09 | 0.45*** |
| | (3.27) | (4.09) | (1.12) | (2.81) |
| *Bcap* | −0.01 | −0.11*** | −0.05 | −0.22*** |
| | (−0.33) | (−2.75) | (−1.38) | (−3.66) |
| Log likelihood | −1040 | −845 | −488 | −688 |
| Observations | 490 | 409 | 285 | 347 |

Asymptotic *t*-statistics are in parentheses.

* Significant at the 0.10 level.

** Significant at the 0.05 level.

*** Significant at the 0.01 level.

[a] The dependent variable is $VI = \log(\text{ISR} * 100)$, where ISR is the input self-sufficiency ratio. If ISR = 0, it is set to 1 before taking log.

[b] $VI_{72}$ is *VI* measured in 1972. *Gas* is a dummy variable equal to one if the input is gaseous, or zero if not. *Pu* is the standard error of residuals from the de-trending regression: $\log(P_{it}) = a_i + b_i t + u_{it}$, where $P_{it}$ is the average price of the $i$th input in year $t$. The regression is run for each of the inputs and each decade ending in 1972, 1982 and 1992, using annual prices of the 10 prior-and-inclusive years. *Scale* is the produce's capacity normalized by the average capacity of all producers. *Bcap* is the average capacity of input plants divided by the average capacity of product plants.

estimated coefficients from the Tobit regressions for the three sampling years. Different from the previous results in Table 6, the effect of *Pu* is no longer significant in 1982 while the interactive effect of *Pu* and *Gas* is positive and significant in 1972 and 1982, but not significant in 1992. Also worth noting, after including the interaction term, the coefficient of *Gas* becomes insignificant to weakly negative across the regression models. The evidence suggests that the joint effects of price uncertainty and asset specificity dominate the individual effects in explaining vertical integration. The estimated coefficients of *Scale* and *Bcap* maintain their previous signs and levels of significance. As in equation (3), the partial adjustment model run on the 1982 sample yields similar, albeit weaker, results, compared with the results in equation (2).

The evidence suggests that the positive reaction of vertical integration to input price uncertainty is attributed to producers requiring gaseous inputs. The gaseous input users are subject to a higher degree of asset specificity than are the non-gaseous input users, because their transaction possibilities are contrived by the high transportation and

Table 8
Mean fractions of producers' capacity located in the Gulf Coast States of Texas and Louisiana

| Year | Number of producers | All producers | Producers using gaseous inputs | Producers using non-gaseous inputs | *T*-statistic for diffirence in means |
|---|---|---|---|---|---|
| 1972 | 490 | 0.40 | 0.47 | 0.30 | 4.11*** |
| 1982 | 409 | 0.47 | 0.50 | 0.40 | 2.23** |
| 1992 | 347 | 0.52 | 0.56 | 0.44 | 2.29** |

* Significant at the 0.10 level.
** Significant at the 0.05 level.
*** Significant at the 0.01 level.

storage costs of the gas (Mulherin, 1986a). The expected high costs of supply disruption motivate the gaseous input users to adopt high degrees of input self-sufficiency in response to price uncertainty. The evidence is therefore consistent with the transaction cost prediction.

Vertical integration in the 1992 sample cannot be related to price uncertainty, as none of the coefficients of *Pu* and the interaction terms in Tables 6 and 7 is statistically significant. Several market developments may have reduced the need for using vertical integration to deal with price uncertainty in the more recent period. Middlemen may have increased their roles in aligning buyers and sellers and in collecting and aggregating pricing information (Ching, 1986; Goldberg and Erickson, 1987). Globalization and increasing openness of markets may have served the same purpose of reducing the costs of arm's length transactions. The introduction of modern risk management instruments and techniques[24] may have enhanced firms' ability to mitigate the costs of price fluctuations (Sykuta, 1996). These hypotheses are left for future research.

### 4.3.3. Effects of industry agglomeration

The Gulf of Mexico in the US region has a high concentration of petrochemical plants. This is illustrated in Table 8, where I report mean percentages of producers' capacity located in the Gulf Coast states of Texas and Louisiana. In 1972, petrochemical producers on average had 40% of their production capacity located in the Gulf region. Over time, the capacity share increased to 47% in 1982 and then to 52% in 1992. The pattern of capacity concentration is particularly significant for producers requiring gaseous inputs. For these producers, their average Gulf region capacity shares are 47%, 50%, and 56% in the three respective years. In contrast, for producers using non-gaseous inputs, the figures are much lower: 30%, 40%, and 44%, respectively. The differences in the Gulf region output capacity shares between the two groups of producers are statistically significant in all sampling years.

Industry infrastructures in the region play an important role in the capacity concentration. The region has integrated pipeline systems connecting users and suppliers of

[24] With proper risk management tools, companies can enter into independent supply contracts without having to worry about price risk. See Chang and Joseph, 1997, "Shell Launches Firm to Help Manage Risk in Price Fluctuation", *Chemical Marketing Reporter*, July 28.

several gaseous inputs. Commercial storage facilities are also abundant.[25] These infrastructures make possible transportation over longer distances and storage of larger amounts, which in turn facilitate transaction possibilities for producers and suppliers. Transactions carried out in the Gulf region are expected to have lower degrees of asset specificity relative to transactions in other regions.

To examine the effects of the industry agglomeration on producers' vertical *NGulf*, are created. *Gulf* equals one if a producer has plant(s) in the Gulf Coast states of Texas and Louisiana; if not, it equals zero. *NGulf* equals one if the producer does not have any plant located in the two Gulf Coast states; if not, it equals zero. The regression models of Table 7 are revised to allow the *Gulf* and the *NGulf* variables to interact separately with $Pu * Gas$.

The regression results are presented in Table 9. The estimated coefficients of *Gas*, *Pu*, *Scale*, and *Bcap* are of similar magnitudes and significance levels as those reported in Table 7. The focus here is the pair of the interaction terms. In the 1972 regression, the estimated coefficient of $Pu * Gas * Gulf$ is not significant while the coefficient of $Pu * Gas * NGulf$ is positive and significant, (1). The evidence suggests that, prior to 1973, if gaseous input users are located in the Gulf region, it is not necessary to change their degrees of vertical integration in response to price uncertainty. Increasing vertical integration is necessary only for producers in the non-Gulf region. In the 1982 regressions, both the coefficients of $Pu * Gas * Gulf$ and $Pu * Gas * NGulf$ are significantly positive ((2) and (3)). The results suggest that, after the oil price shocks, price uncertainty increases the vertical integration of the firms requiring gaseous inputs, regardless of their geographic locations. Lastly, vertical integration in the 1992 sample cannot be related to input price uncertainty, as none of the coefficients of *Pu* and the interaction terms is significant, (4).

The overall evidence suggests that industry agglomeration facilitates transaction possibility, reduces the degree of asset specificity in transactions, and therefore weakens the effect of price uncertainty on vertical integration. However, if price uncertainty is high, merely concentrating in one region is not sufficient to solve contracting problems.

### 4.4. Alternative explanations for organizational change

In this section, I examine two alternative hypotheses to explain vertical integration in the petrochemical industry: price controls and market power.

#### 4.4.1. Price controls

A short-term but potentially important factor that hampered price adjustment in the petrochemical input markets is the general price control instituted by the Nixon Administration during 1971 to 1974. Between 1973 and 1974, the price control coupled with the oil embargo created a severe scarcity of petrochemical inputs. During that period, many suppliers could not produce sufficient amounts to meet their contract

[25] Large quantity storage is made by cylindrical tanks with large capacities, underground caverns, or jugs leached out of underground salt domes.

Table 9
Tobit regressions of the effects of industry agglomeration on vertical integration[a]

| Independent variable[b] | 1972 | 1982 | | 1992 |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| *Intercept* | 1.98*** | −0.01 | −2.95*** | 1.35 |
| | (4.60) | (−0.00) | (−2.63) | (1.28) |
| $VI_{72}$ | | | 1.04*** | |
| | | | (14.85) | |
| *Gas* | 0.46 | −5.31* | −3.12 | 1.14 |
| | (0.63) | (−1.83) | (−1.46) | (0.82) |
| *Pu* | −3.43 | 6.64 | 6.66* | 0.63 |
| | (−1.27) | (1.30) | (1.65) | (0.13) |
| *Pu* ∗ *Gas* ∗ *Gulf* | 7.54 | 26.58** | 14.84* | 0.3 |
| | (0.73) | (2.30) | (1.74) | (0.04) |
| *Pu* ∗ *Gas* ∗ *NGulf* | 15.39** | 28.38*** | 14.00* | 0.97 |
| | (1.89) | (2.48) | (1.65) | (0.09) |
| *Scale* | 0.39*** | 0.46*** | 0.08 | 0.45*** |
| | (3.54) | (4.18) | (1.00) | (2.81) |
| *Bcap* | −0.02 | −0.12*** | −0.05 | −0.22*** |
| | (−0.66) | (−3.00) | (−1.38) | (−3.66) |
| Log likelihood | −1039 | −844 | −488 | −688 |
| Observations | 490 | 409 | 285 | 347 |

Asymptotic *t*-statistics are in parentheses.
*Significant at the 0.10 level.
**Significant at the 0.05 level.
***Significant at the 0.01 level.
[a]The dependent variable is *VI* = log(ISR ∗ 100), where ISR is the input self-sufficiency ratio. If ISR = 0, it is set to 1 before taking log.
[b]$VI_{72}$ is *VI* measured in 1972. *Gas* is a dummy variable equal to one if the input is gaseous, or zero if not. *Pu* is the standard error of residuals from the de-trending regression: $\log(P_{it}) = a_i + b_i t + u_{it}$, where $P_{it}$ is the average price of the $i$th input in year $t$. The regression is run for each of the inputs and each decade ending in 1972, 1982, and 1992, using annual prices of the 10 prior-and-inclusive years. *Gulf* (*Ngulf*) is a dummy variable equal to one if a firm has (does not has) plant(s) in the Gulf-Coast states of Texas and Louisiana, or zero if not. *Scale* is the produce's capacity normalized by the average capacity of all producers. *Bcap* is the average capacity of input plants divided by the average capacity of product plants.

obligations because of not being able to pass their input costs on to their customers by sufficiently raising contract prices. They instead invoked allocation programs to distribute the limited quantities among their customers. The allocation scheme could be quite ambiguous and create buyers' uncertainty about been unfairly rationed. An aggravating factor of the allocation uncertainty is related to spot markets. During the price control period, the spot markets became active gray markets where inputs were bought and sold at prices much higher than the controlled contract prices. The large price dispersions might have tempted suppliers to long spot buyers while shorting their contract buyers, hence damaging the effectiveness of contract governance before the control was lifted in 1974. As Stigler's (1951) theory suggests, the firms might have integrated into input stages to circumvent the input markets distorted by the price control. Price controls have been found to affect governance choices in other industries.

Similar to the petrochemical industry, the regulation of wellhead prices in the natural gas industry led to a scarcity condition in the early 1970s (MacAvoy and Pindyck, 1973). Hubbard and Weiner (1986) study the effects of the price control on provisions of contracts between natural gas producers and pipelines. They find that the price control increased the use of the take-or-pay provision, due to non-price competition among pipelines. In particular, they report that the use of the take-or-pay provision increased sharply after 1973, because the non-price competition was intensified by the increased demand for gas and the expectation of decontrol in the near future.[26]

To evaluate the effects of the price control on vertical integration in the petrochemical industry, I study input price jumps around the two oil price shocks. The regression model of Table 6 is amended with two additional independent variables, *Jump73* and *Jump79*, then re-estimated using the 1982 sample. For a given input, *Jump73* is defined as the natural logarithm of the ratio of the 1974 average price to the 1973 average price. *Jump79* is similarly defined as the natural logarithm of the ratio of the 1980 average price to the 1979 average price. My focus is *Jump73*. If the price control was binding, one expects to observe jumps in the input prices immediately after the price control was alleviated in early 1974. Furthermore, the more binding the price control was, the greater the extent of the price jump should be. To be consistent with the predicted effects of the price control, one should observe a positive reaction of the firms' vertical integration to *Jump73*.

Table 10 presents the regression results. The estimated coefficients of *Gas*, *Scale*, and *Bcap* are of similar magnitudes and significance levels as in Table 6. Here I focus on the price jump variables. As in equation (1), vertical integration is unrelated to the price jumps: the coefficients of *Jump73* and *Jump74* are insignificant. Equation (2) jointly considers the effects of *Pu* and the price-jump variables. The coefficient of *Pu* remains positive and significant at the 1% level. The coefficient of *Jump73* turns negative and significant. The coefficient of *Jump79* stays insignificant. In sum, the positive effect of input price uncertainty observed in the 1982 sample cannot be explained by the price jumps immediately after the two oil price shocks. In particular, the insignificant-to-negative coefficients of *Jump73* do not support the view that vertical integration of the firms was uniquely induced by the allocation uncertainty created by the price control and the input price hikes during 1973 to 1974. The evidence is more consistent with the view that the firms' vertical integration was affected by the general input price uncertainty in the decade after 1973.

### *4.4.2. Market power*

One rationale for petrochemical firms to engage in input production is that the firms can extend their market power to the input markets, for example through foreclosing competitors' access to the inputs. To investigate this hypothesis, I study the concentration of input markets. The ability of a firm using vertical integration to extend market power is positively affected by the concentration of the market in question. A Herfindahl index is constructed to capture input market concentration. The index is measured as the

[26] The National Gas Policy Act of 1978 deregulated wellhead prices.

Table 10
Tobit regressions of the effects of the input price jumps in 1973 and 1979 on vertical integration[a]

| Independent variable[b] | (1) | (2) |
|---|---|---|
| *Intercept* | 1.52 | −0.91 |
| | (1.44) | (−0.73) |
| *Gas* | 1.28*** | 1.65*** |
| | (3.04) | (3.83) |
| *Pu* | | 21.87*** |
| | | (3.62) |
| *Jump73* | 0.06 | −3.93** |
| | (0.04) | (−2.36) |
| *Jump79* | 0.51 | 0.60 |
| | (0.54) | (90.65) |
| *Scale* | 0.46*** | 0.43*** |
| | (4.18) | (3.90) |
| *Bcap* | −0.10** | −0.11*** |
| | (−2.17) | (−2.44) |
| Log likelihood | −852 | −845 |
| Observations | 409 | 409 |

Asymptotic $t$-statistics are in parentheses.

* Significant at the 0.10 level.

** Significant at the 0.05 level.

*** Significant at the 0.01 level.

[a] The 1982 sample is used in the regressions. The dependent variable is $VI = \log(\text{ISR} * 100)$, where ISR is the input self-sufficiency ratio. If $ISR = 0$, it is set to 1 before taking log.

[b] *Gas* is a dummy variable equal to one if the input is gaseous, or zero if not. *Pu* is the standard error of residuals from the de-trending regression: $\log(P_{it}) = a_i + b_i t + u_{it}$, where $P_{it}$ is the average price of the $i$th input in year $t$. The regression is run for each of the inputs and each decade ending in 1972, 1982, and 1992, using annual prices of the 10 prior-and-inclusive years. *Gulf* (*Ngulf*) is a dummy variable equal to one if a firm has (does not has) plant(s) in the Gulf-Coast states of Texas and Louisiana, or zero if not. *Jump73* (*Jump79*) is the natural logarithm of the ration of the 1974 (1980) average price to the 1973 (1979) average price. *Scale* is the produce's capacity normalized by the average capacity of all producers. *Bcap* is the average capacity of input plants divided by the average capacity of product plants.

sum of the squared capacity shares of firms producing the input. The value of the index ranges between 0 and 1 and increases with the market concentration level. Panel A of Table 11 reports summary statistics of the index. From the mean and median statistics, petrochemical input markets generally have low levels of concentration. The mean is only 0.09, 0.10, and 0.09 in 1972, 1982, and 1992, respectively. The median is 0.08, 0.07, and 0.07 in the three respective years. Even at the maximum, the concentration level is not high: 0.32, 0.33, and 0.35, respectively. The low input market concentration casts doubt on market power as an explanation for the vertical integration in the industry.

To further investigate the market power hypothesis, I compare the mean input concentration between integrated producers (with input plant ownership) and other non-integrated producers (without input plant ownership). The market power hypothesis predicts that a producer is more likely to integrate vertically (own input plants) when the input market is more concentrated. It turns out that vertical integration and market

Table 11
Statistics of the Herfindahl index of petrochemical input market concentration[a]

| | 1972 | 1982 | 1992 |
|---|---|---|---|
| *Panel A: Overall summary statistics* | | | |
| Mean | 0.09 | 0.10 | 0.09 |
| Standard error | 0.06 | 0.06 | 0.06 |
| Median | 0.08 | 0.08 | 0.07 |
| Maximum | 0.32 | 0.33 | 0.35 |
| Minimum | 0.03 | 0.05 | 0.06 |
| *Panel B: Mean statistics by producers' input plant ownership* | | | |
| Producers that own input plants | 0.08 | 0.09 | 0.09 |
| Producers that do not own input plants | 0.11 | 0.12 | 0.11 |
| *T*-statistic for difference in means | −4.68*** | −4.01*** | −3.02*** |
| *Panel C: Mean statistics by input substance* | | | |
| Producers that use gaseous inputs | 0.05 | 0.07 | 0.06 |
| Producers that use non-gaseous input | 0.13 | 0.14 | 0.14 |
| *T*-statistic for difference in means | −16.54*** | −13.97*** | −12.36*** |

* Significant at the 0.10 level.
** Significant at the 0.05 level.
*** Significant at the 0.01 level.
[a] The Herfindahl index of an input market is the sum of the squared capacity shares of individual input firms. The sample includes 490, 409, and 347 firms producing 49 products derived from 24 inputs in 1972, 1982, and 1992.

concentration are related, but in a direction opposite to what is predicted by the hypothesis. As reported in Panel B of Table 11, producers facing less concentrated input markets are more likely to own input plants than producers facing more concentrated markets. The differences in the mean concentration index between the integrated and non-integrated firms are negative and statistically significant in all of the three sampling years.[27] The evidence from this analysis suggests that market power cannot explain the vertical integration of petrochemical producers into input stages.

## 5. Conclusion

I study vertical integration in the petrochemical industry with a focus on the 1970s, the period of the oil price shocks. I find that producers' degrees of input self-sufficiency

[27] The negative relation between market concentration and vertical integration is likely a spurious relation caused by gaseous inputs. As shown in the regression analysis (Tables 6 and 7), producers of gaseous inputs are more likely to integrate vertically. At the same time, the markets for gaseous inputs are also less concentrated. This is shown in Panel C of Table 11, where I compare the market structure between gaseous and non-gaseous inputs in 1972, 1982, and 1992. The number of gaseous input producers is over twice as many as the number of non-gaseous input producers. The Herfindahl concentration index of the gaseous inputs is two-times lower than that of the non-gaseous inputs.

are positively related to the price uncertainty during that period. The positive reaction of vertical integration to the input price uncertainty mainly occur among producers requiring gaseous inputs that are subject to high degrees of asset specificity. Vertical integration in the industry is also related to industry agglomeration. I report that, prior to the first oil price shock, the extents of vertical integration of firms located along the US Gulf Coast were less affected by price uncertainty than firms located in other areas. However, after the price shock, the firms' extents of vertical integration were positively affected by input price uncertainty, regardless of their geographic locations.

The findings generally support the transaction cost view that uncertainty provoked by dramatic events reduces the advantage of contracts relative to vertical integration in governing relationship-specific transactions. The paper also provides evidence consistent with the reputation, production cost, and capacity balance effects articulated in the literature. In contrast, several rival hypotheses of transaction cost are rejected in the paper. Vertical integration in the industry is not motivated by price controls, nor is by market power.

This paper has demonstrated the value of industry study in analyzing organizational changes and issues in financial economics. Related examples are Mulherin's (1986b) analysis of vertical integration and contracting in the natural gas industry, Zingales' (1998) analysis of exit and financing in the trucking industry, and Kole and Lehn's (1999) paper on the adaptation of governance structure in the airline industry. These studies have used exogenous shocks to form natural experiments in one industry, which allow empirical tests of theories in great detail and precision.

There are abundant opportunities for applying industry research on topics in finance and organizational economics. Future industry studies might include analysis of deregulation and the electric utility industry, technological change and the telecommunications industry, and the end of the Cold War and restructuring in the defense industry. More efforts toward this direction are warranted.

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