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UPSTREAM VERTICAL INTEGRATION IN THE ALUMINUM AND TIN INDUSTRIES

A Comparative Study of the Choice between Market and Intrafirm Coordination

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This paper explores whether Williamson's theory of vertical integration holds for the upstream stages of the aluminum and tin industries. It concludes that the structure of these industries is broadly consistent with Williamson's predictions: the higher degree of upstream vertical integration in aluminum can be explained by greater scale economies, higher barriers to entry, higher transportation costs, and greater asset specificity. Similarly, differences in vertical integration within the tin industry can be explained in terms of the same variables.

1. Introduction

In his 1971 seminal paper, 'The Vertical Integration of Production: Market Failure Considerations', Oliver Williamson argued that successive, technologically-separable stages of production will be vertically integrated when the cost of coordinating them within the firm is lower than that experienced through markets or contracts. Testing Williamson's theory of vertical integration requires a thorough understanding of the characteristics of transactions, such as number of parties, asset specificity, and uncertainty. Because many of those characteristics are subtle, most of the tests have followed a microeconomic approach [Monteverde and Teece (1982), Masten (1984)].

Not surprisingly, much of the data necessary for such tests is not readily available. This paper provides the first estimates of the extent of upstream vertical integration in the tin industry, and uses a transaction–cost frame-

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work to explain why the extent of upstream vertical integration is lower in tin than in aluminum.

The next section analyzes the key variables which, in a transaction cost framework, can be expected to affect a firm's propensity to integrate. Sections 3 and 4 apply the model to the aluminum and tin industries. Section 5 evaluates the model's explanatory power.

2. The transaction cost model of vertical integration

Williamson (1971, 1975, 1985) argues that vertical integration will be favored in thin or narrow markets to avoid bargaining and opportunistic behavior. When the number of parties to the exchange is large, competition among traders disseminates all relevant information in the form of prices, reduces haggling, and discourages fraud. The terms of trade are exogenous, and it does not pay to invest in strategic bargaining. Incentives for opportunism are also minimal because the aggrieved party can turn to another supplier/buyer.

Inefficiencies arise when the number of actual or potential traders at each stage is limited. With a small number of traders, strategic bargaining becomes profitable. A party to the exchange can now be 'held up' by another party, because he cannot turn to an alternative trader. The potential loss to such an exploitation is the difference between the value of the asset in its current use and its value in its next best use, i.e., its appropriable quasi-rent [Klein, Crawford and Alchian (1978)].

Contracts provide some protection against this risk. They specify ex ante the terms and conditions of the trade and the compensation to be paid in case of breach. The protection offered by contracts is adequate when the degree of uncertainty surrounding the transaction is limited. As uncertainty increases, it becomes impossible to anticipate and to cover oneself against all possible contingencies. Vertical integration then becomes the most efficient governance mode [Williamson (1985)].

Yet hierarchical coordination has its own costs. A firm that takes over its customer or supplier is forced to take up new activities or to enter new markets, on which it has little information. This raises management costs. The extension of the firm also results in the replacement of price by behavior constraints [Hennart (1982)]. Workers must now be monitored and the cost of supervision must be deducted from the gains obtained from eliminating market transaction costs.

Transaction cost theory thus isolates three key variables which determine the desirability of vertical integration: the number of actual or potential parties at each stage, the level of quasi-rents that can be captured by opportunism, and the degree of uncertainty surrounding the transaction.

Two variables affect its cost: the dissimilarity between upstream and downstream activities, and the cost of monitoring employees.

2.1. Number of traders at each stage

The number of traders at each stage is itself a function of technical, economic, and political variables. Economies of scale, absolute capital requirements, and the availability of the knowledge necessary to operate in the industry determine both the number of efficiently-sized production units at each stage and the ability of firms to enter each stage and thus avoid being shut off from their supplies or markets. High transportation costs also further segment the market because they reduce the number of potential buyers facing each seller (and vice versa). Government intervention may have an independent effect on the number of buyers or sellers. Governments can, for example, encourage vertical integration by establishing monopolies where economic processes would ensure competition. Lastly, what was ex ante a competitive situation may be transformed ex post into a bilateral exchange relation as parties find it profitable to make durable and transaction-specific investments to support the exchange.

Williamson (1985) identifies four types of specificities, of which three are relevant in the context of mineral industries. The first is *site specificity*, which is present when buyers and sellers are in contiguous locations in order to minimize inventory and transportation costs. The second is *physical asset specificity*: it arises when one or both parties to the transaction invests in equipment specially designed to carry out the transaction, and which has a lower value in other uses; the characteristics of the production process, namely the gains realized by using specially-designed plants to treat heterogeneous inputs, determine the extent of physical asset specificity. Lastly, specificity may take the form of *dedicated assets*, investments which are undertaken to support a transaction with a particular supplier/customer; assets become dedicated when economies of scale are significant at both the upstream and downstream stages.

2.2. Potential for opportunistic exploitation

At a given level of specificity, the potential for opportunistic exploitation will vary with certain characteristics of the production process. Assets which are large, immobile, and long lived are especially likely to be 'held up' by an opportunistic trader. The cost incurred from an interrupted input supply will be greater if that input is bulky or perishable (and thus costly to store) and if it is used in fixed, rather than variable, proportions. The same is true for flow, as opposed to batch, processes. Lastly, the plant's cost structure is also relevant. The greater the share of fixed costs in total costs, the greater the financial burden imposed by a shortage of inputs (or a loss of sales).

2.3. Uncertainty

The higher the level of uncertainty surrounding the transaction, the more costly it will be, ceteris paribus, to use contracts to coordinate successive production stages.

The transaction cost framework thus suggests a number of variables susceptible to increase the costs of market transactions, namely economies of scale, other barriers to entry, transportation costs, storage costs, and input heterogeneity. Furthermore, the model suggests that, everything else constant, opportunism is likely to be seen as a greater risk for plants using continuous processes and for plants which are immobile. In the next section the model is applied to the aluminum industry.

3. Vertical integration in the aluminum industry

Aluminum production consists of four main stages, mining, refining, smelting, and fabricating. The first step in producing aluminum is the mining of bauxite. Bauxite is then refined into alumina by mixing it with caustic soda. Primary aluminum metal is produced from alumina by electrolysis. Downstream stages include fabrication and/or manufacture of final products using aluminum. In this piece we are focusing on the first two stages, bauxite mining and refining.

Aluminum is one of the most vertically integrated mineral industries. In 1976, 91 percent of the total volume of bauxites was transferred within vertically-integrated firms [Hashimoto (1983) p. 18]. In the following pages, I analyze the reasons for such a high degree of vertical integration, relying heavily on Stuckey's (1983) excellent recent study.

Three factors combine to make the market for bauxites bilaterally monopolistic or oligopolistic: bauxite mining and refining require high minimum efficient scales; refineries are specifically designed to handle a particular type of bauxite; and the high cost of transporting bauxites further segments the market. The potential cost of trading in a thin bauxite market is particularly high since bauxite refining is a continuous process of high capital intensity. Lastly, the bauxite market has been affected in the last twenty years by significant and unpredictable changes.

3.1. Economies of scale

The number of buyers and sellers of bauxite is limited by high minimum efficient scales (MES) at both the mining and refining stages (Table 1). The

Table 1

Economies of scale and barriers to entry in aluminum.

	Bauxite mining	Alumina refining
Minimum efficient scale (MES) (thousand tons/year)	5,000–8,000	500–1,000
Cost of MES (million U.S.$)	500	500–1,000
MES as percent world capacity	8–10	4
World capacity 1981 (thousand tons/year)	-	39,295
World production 1981 (thousand tons/year)	85,729	32,335
Number of plants c. 1980	-	80
Barriers to entry	substantial	substantial

Source: Stuckey (1983); United Nations (1981).

MES of bauxite mines has grown substantially in recent decades as the exhaustion of known deposits has pushed aluminum makers towards poorer and/or less accessible deposits. An efficiently-sized bauxite mine now has an 8 million tone capacity, and costs US$ 0.5 billion. Such a mine adds 8 to 10 percent to the world's bauxite output. Penalty for less than efficient size is significant [Stuckey (1983, p. 78)].

Alumina refining is also subject to substantial economies of scale. The MES of alumina refineries is between 500,000 and 1 million tons, about four percent of the world's total capacity. The long-run average cost curve rises significantly below MES [Stuckey (1983, p. 16)].

3.2. *Barriers to entry*

Barriers to entry into bauxite mining and refining are high due to the high cost of an efficiently-sized mine (about $500 million) and refinery ($500 to 1000 million).[1] Technology can also be a barrier for new entrants into alumina production: although the Bayer process used in alumina refineries is well known, optimal adaptation to feedstocks and to the relative prices of inputs can be obtained only through experience [Stuckey (1983, pp. 163–165)].

3.3. *The nature of bauxites*

Aluminum is the second most abundant metal in the earth's crust. The principal aluminum ore is bauxite, but the metal can also be extracted, though at higher cost, from other ores. Bauxite is not an homogeneous commodity: there are two basic types, one containing alumina trihydrate, the other monohydrate alumina. Both types are refined into alumina by mixing them with a caustic soda liquor at a suitable temperature, but monohydrates require higher temperatures and higher concentration of caustic soda than

[1] As argued by Bain (1956), the cost of raising capital increases with the size of finance requirements to establish a plant at MES. This assumes imperfect financial markets.

trihydrates. Optimal digestion also calls for substantive differences in the design of the digestion chamber and of associated components. As a result, alumina plants are designed to treat one particular type of bauxite. Switching costs are significant. Running one type of bauxite in refineries designed for the other type increases costs by 20 to 100 percent [Stuckey (1983, p. 53)]. Design modifications are costly and time consuming. Moreover, the blending of bauxites is only marginally helpful [Stuckey (1983, p. 55). The need to tailor a refinery to a specific type of bauxite tends to lock bauxite mines and alumina refineries into trading conditions that approach bilateral monopoly.

3.4. Transportation costs

The market for bauxite is further segmented by high transportation costs. Bauxite is a low value bulk commodity: ores contain only 10 to 25 percent aluminum, and aluminum metal is relatively cheap (at least in comparison to tin or nickel). As a result, the market for bauxite is regional: 77 percent of the bauxite imported by the United States in 1976 came from the Caribbean region, while Japan imported close to 90 percent of its bauxite from Australia and Indonesia [Rodrik (1982, pp. 203–204)].

3.5. Potential for opportunistic exploitation

Because of high economies of scale and barriers to entry at both the mining and refining stages, of high transportation costs, and of the specificity of bauxites to refineries, bauxite is traded on thin markets. The potential for opportunistic exploitation is heightened by the characteristic of the production process. Bauxite has no major alternative use.[2] Mining and refining require expensive, immobile plants, which have a negligible value in other uses. Bauxite refining is capital intensive, capital charges amounting to about 35 percent of the cost of production [Hashimoto (1983, p. 47)]. It is also a continuous process, making input interruption costly [Brubaker (1967, p. 97)]. As we have seen, the costs of switching to an alternate input source are significant. Stockpiling of bauxite is costly, given its low grade. Additionally, some types of bauxite, such as Jamaican bauxites, must be stored under cover [Stuckey (1983, p. 49)].

3.6. Long-term contracts

High transportation costs and the need to design alumina refineries to fit a particular bauxite type thus lock mine and processor in a bilateral relation-

[2]Eighty-five percent of the bauxite mined is used to produce alumina.

ship. To organize that relationship through spot markets would be hazardous, given the significant investments which must be made at each stage to benefit from economies of scale.

Contracts have been used to coordinate mines and refineries. Because of the very large specific investments at stake, they tend to be very long-term, typically 20 to 25 years. Over such a long time span they cannot effectively protect the parties against changes in the environment. The recent experience of long-term bauxite contracts supports Williamson's claim that the efficiency of such contracts is inversely related to the degree of asset specificity and to the extent of uncertainty surrounding the transaction.

The volume of arm's length sales of bauxite increased in the early 1960s when two companies, Comalco and Gove Alumina, started to ship Australian bauxite to Japan under long term contracts. The largest of such contracts were between Comalco and Japanese and European aluminum makers. Contract prices were denominated in U.S. dollars, with production cost escalation clauses [Smith (1978, p. 255)]. The revaluation of the Australian dollar subsequent to the breakdown of Bretton Woods and the ensuing world depression reduced by half the price received by Comalco. From 1972 on, Comalco made strong attempts to renegotiate prices, and by 1977 seemed to have obtained some meausre of satisfaction, but was still pressing for price adjustments. The turbulent seventies also affected Comalco's Japanese customers. The rise in the price of crude oil made smelting in Japan uneconomic, and between 1980 and 1982 five Japanese smelters, accounting for 68 percent of that country's smelting capacity, were closed [Macmillan (1985, p. 33)]. According to Stuckey (1983, p. 125), the disappointing performance of these contracts persuaded Comalco to reduce its dependence on arm's length customers by developing tied outlets for its bauxite. Since 1967 Comalco has set up, in joint venture with other firms, two alumina refineries which take exclusively Comalco bauxite. As a result, the percentage of Comalco's bauxite sold through contract decreased from 80 percent in 1965 to about 20 percent in 1982. Comalco's experience must have been shared by other arm's length sellers, for Stuckey's estimates show that the percentage of world bauxite traded at arm's length, which had reached 17 percent in the mid-seventies, had fallen to about 10 percent by 1978 [Stuckey (1983, p. 111)].

3.7. Conclusion

The characteristics of the bauxite market, high and similar economies of scale at both stages, high transportation costs, and high degree of asset specificity, suggest that spot markets and contracts are today an inefficient method of coordinating buyers and sellers of bauxites. As expected, vertical integration is the method used for the bulk of bauxite transactions. Long-term contracts play a subsidiary role, but they appear to constitute a second best solution, and their importance is declining. In the next section we investigate whether the same considerations can explain the extent of vertical integration in tin.

4. Vertical integration in the tin industry

The tin industry consists of three main stages, mining/concentrating, smelting/refining, and the manufacture of tin-containing products. Tin ores are found in two types of deposits, alluvial and lode. The concentrates obtained from these ores are smelted in reverberatory, rotary, or electric furnaces and refined by injection of oxygen or by electrolysis. In this paper, we are concerned with the first two stages.

Overall, the tin industry exhibits a low degree of upstream vertical integration. In 1981 the share of tin concentrates that was sold to smelters through market channels (spot sales or long-term contracts) was about 60 percent. As table 2 shows, there are significant geographical differences in the extent of integration. In Thailand, Malaysia and Australia, most concentrates are sold at arm's length to smelters. Vertical integration, on the other hand, prevails in Bolivia, Brazil, South Africa, Indonesia, and the United Kingdom. For the sake of brevity, the discussion will focus on the two polar cases, Thailand–Malaysia–Australia and Bolivia.

4.1. The extent of vertical integration.

In Malaysia, Thailand, and Australia, smelters are not vertically integrated with the mines. Billiton, the owner of the large Thaisarco plant smelting almost all of Thailand's output, has only a very limited involvement in mining. It obtains almost all of its ores by arm's length purchases from a large number of small producers. Two smelters of roughly similar size and both located near Penang, in Malaysia, the Datuk Keramat Smelter (formerly Eastern Smelting) in Georgetown, and the Malaysia Smelting Corporation (formerly Straits Trading Co.) in Butterworth, smelt the whole of Malaysia's output of tin concentrates and half of Australia's. Up until 1982, Malaysian tin mining companies had no major stakes in the smelters.[3] The smelters held minority stakes in a very small number of European tin dredging companies. There are no equity links between Australian mining concerns and the Malaysian smelters.

The Penang market is the mechanism used to price the concentrates obtained from the mines.[4] Up until 1940, both Malaysian smelters competed

[3]In 1982 the state-controlled Malaysia Mining Corporation (MMC) took a 42 percent interest in the Straits Trading Company and the smelter took the name of Malaysia Smelting Corporation.

[4]In 1984 the Penang market was replaced by the Kuala Lumpur Tin Market, but this has not entailed any significant change.

Table 2
Backward vertical integration in the tin industry, 1981 (metric tons of tin-in-concentrates).[a]

Country	Output	Percent integrated
Bolivia	27,612	54
Malaysia	59,938	25
Thailand	31,474	3
Australia	12,083	3
Indonesia	35,319	82
Brazil	7,298	82
South Africa	2,801	73
United Kingdom	3,869	33
World total	192,726	39

[a]Information on vertical integration was obtained from a variety of sources, including *World Tin Mining*, 1982 *Edition*, *Tin Statistics*, various issues of *Minerals Yearbook* and *Tin International*, annual reports of the major companies, and personal interviews with industry observers and participants. Data could be obtained for 97 percent of the tin production of the non-communist world (Mainland China, the U.S.S.R., Laos, Vietnam, Czechoslovakia, and East Germany are excluded). In some cases, production figures reported to the International Tin Council differ from national statistics. When faced with divergent data, I have used the most complete and consistent set of figures available. Thus I have used official Bolivian statistics for Bolivia as reported in Ayub and Hashimoto (1985) because they provide information on sales of concentrates to ENAF. Comibol's output for 1981 is, according to those figures, 2,200 tons lower than that recorded in ITC publications. Other discrepancies exist for Zaire and Brazil. I was unable to obtain any information on the extent of vertical integration in Spain and Portugal. Sales of concentrates by Comibol to ENAF were considered to be intrafirm, because both are state-owned enterprises. All production was deemed to be vertically integrated whenever the same firm had a substantial (more than 10%) ownership in both mine and smelter.

to buy concentrates from the various producers. Since then, the two Malaysian smelters, acting in concert, solicit confidential bids from buyers of tin metal. They match the volume of tin-in-concentrates received that day from the mines aginst bids for tin ranked in descending order of value. If bids exceed the amount of tin that the smelter is putting on sale, the cut-off point where the bids are equal to the supply determines the Penang price for that day. All bids above the cut-off point receive contracts in full at the cut-off price. The remaining quantities of tin (if any) are sold to those bidding at the marginal price. Smelters then pay miners the tin content of their concentrates multiplied by the day's tin price on the Penang market, minus penalties for impurities and charges for transport and handling.

35 to 38 percent of all physical tin is transacted on the Penang market, but the influence of that market is even greater than those figures would suggest: a significant volume of concentrates is also bought by non-Malaysian smelters on the basis of the Penang price. For example, the Thaisarco smelter in Thailand, and Associated Tin Smelters, the main Australian smelter, purchase concentrates at the Penang price.

Market processes thus coordinate tin mining and tin smelting in Malaysia, Thailand and Australia. This is in marked contrast to the situation in Bolivia. Vertical integration has been prevalent in the Bolivian tin industry since its beginnings in the early 1900s. Bolivian tin mining has always been concentrated into the hands of a few producers, of which Simon Patino was the largest. In 1917 Patino took a minority interest in the British smelter which was buying his concentrates, and by 1929 was its sole owner. During the interwar period other major Bolivian tin producers, such as the Llallagua company and Hochschild, made attempts to integrate into smelting, while Asarco, owner of a U.S. smelter handling Bolivian ores, developed a captive mine in Bolivia. The nationalization of Patino's Bolivian assets in 1952 broke for a while the vertical ties between mining and smelting. The government-owned Corporacion Minera de Bolivia (COMIBOL), heir to Patino's Bolivian mines and to those of two other nationalized groups, immediately made plans for building its own smelters in Bolivia. The first one came on line in 1971, and today Bolivia has enough capacity to handle the whole of its output.

Our brief survey of the tin industries of Malaysia, Thailand, Australia, and Bolivia shows that, unlike in the case of aluminum, the tin industry exhibits no general pattern of vertical integration. We will see in the next section that the overall lower degree of vertical integration in tin than in aluminum, as well as the previosly noted geographical differences in the extent of vertical integration in tin, are generally consistent with the predictions of the transaction costs model.

4.2. The market for tin concentrates

Tin is a relatively scarce element. The only tin-bearing mineral of economic importance is cassiterite, or tin oxide, which is found in two very different types of deposits. Secondary or alluvial deposits, which result from the erosion of tin-bearing rock by wind or water, are found in Southeast Asia (Malaysia, Burma, Thailand and Indonesia), Brazil, Central Africa, and parts of Australia. They are low grade, but close to the surface. They can be mined by small scale methods, and are easily concentrated through gravity to 70–77 percent tin. Because they contain few impurities, they can be smelted easily by any smelter.

Primary or lode deposits are higher grade, but are usually deeper underground. They are exploited in Bolivia, South Africa, the United Kingdom and parts of Australia in opencast or underground mines. These ores have a more complex structure, and the resulting concentrate is usually of lower grade. Their efficient treatment requires specific adjustment by smelters.

Although there are differences between the two types of tin deposits, which have led to divergences in the extent of vertical integration within the industry, the following generalizations can be made: (1) Tin mining is, by and large, smaller in scale than bauxite mining. As shown in table 3, an efficiently sized mining unit accounts for less than one percent of world production; mining technology is widely available; (2) Compared to alumina refineries, the MES of smelters is small, and, as shown in table 4, their capital requirement is modest; except for the treatment of low grade ores, smelting tin is a straightforward process. (3) Transportation costs are also much lower for tin concentrates than for bauxite. While the market for bauxite is regional, that for tin concentrates is worldwide. The following sections elaborate on those points.

Table 3 lists the principal methods used to mine tin, their relative importance, their size, and their capital cost. The first five methods (gravel

Table 3

Economies of scale and barriers to entry in tin mining by mining method (1979).

	Gravel pump	Onshore dredge	Offshore dredge	Dulang	Suction boats	Under-ground	Opencast
Number of plants worldwide	1,304	90	24	27,500[c]	2,000[c]	33	23
Relative importance (% total production	28.5	13.2	6.5	1.9	7.5	22	1.7
Cost of unit ($ million)	0.5	15	25	[d]	0.01	12–80	–
Average output (tons/year)[a]	44	295	547	0.1	7	1,333	152
Average output/world production[b] (%)	0.02	0.14	0.27	[d]	[d]	0.66	0.07

[a]Metric tons of tin-in-concentrates.
[b]Excluding Albania, the People's Republic of China, East Germany, Mongolia, North Korea, the U.S.S.R. and Vietnam.
[c]Approximately.
[d]Close to zero.

Source: Thoburn, 1981, pp. 41, 136; Allen and Engel, 1979.

Table 4

Characteristics of some post-war tin smelters.[a]

Name	Grade	Description	Capacity	Year	Cost
	High				
Thai Pioneer	73		3,600	82	8.8
Somirwa	69	2 electric	2,000	78	
Thaisarco	73.5	3 reverbs	15,000	65	12.7
Mentok	70–74	3 rotary	15,000	67	9.1
		3 reverbs	18,000	75	8.6
Makeri	73.5	2 reverbs	14,000	62	
Greenbushes	70	1 electric	1,000	80	
Syriam			1,000	82	4.0
	Medium				
Vinto	42	2 reverbs	7,500	71	27.1
			12,500	77	30.0
Rooiberg	59	2 electric	2,000	81	5.5
	Low				
Vinto	25		10,000	80	71.9

[a]Average grade in percent tin; capacity in metric tons/tin per annum; cost in millions 1980 U.S. dollars. Compiled from Allen and Engel (1979, pp. 91–97); Tin International (March 1985); Minerals Yearbook, various issues; various other trade publications.

pumping, dredging, dulang washing, suction boats, and opencast mining) are used on alluvial deposits. Lode deposits are mined in opencast and underground mines. The table shows that a substantial percentage of alluvial tin is mined by relatively small scale methods. Lode tin is mostly obtained from underground mines. Although the size of these operations varies enormously, this method is, on average, more capital intensive than those used on alluvial deposits.

Alluvial ores can be easily concentrated by gravity using very simple equipment. Lode ores, on the other hand, contain iron and a variety of other metals which are often difficult to separate from the contained tin. Iron is the most troublesome impurity. Bolivian concentrates have the highest iron content and alluvial ores the lowest with Australian and British ores somewhere between those two extremes. Lode ores must be ground and tin separated by a variety of methods including flotation. The concentration process can theoretically eliminate most of the impurities contained in the ore, and produce a high grade concentrate, but at the cost of losing a percentage of the contained tin. These losses can be as high as 88 percent in the case of complex lode ores [Allen and Engel (1979, p. 89)]. The amount of tin loss in the concentration process (the recovery rate) can be reduced by investing in sophisticated concentrating equipment. The final grade of concentrates produced, and the optimal investment in concentration, are the results of economic decisions, as low grade concentrates are more expensive to smelt. In general, the optimal capital intensity of concentrating lode ores will be higher than that used for alluvial concentrates, while lode mines will usually ship concentrates which still contain some impurities and which grade 20 to 60 per cent tin.

Tin metal is produced in two stages, smelting and refining, both performed at the smelter. In contrast to bauxite refining, a range of techniques can be used to smelt and refine tin, depending on the volume and type of concentrates to be treated. Rotary and electric furnaces are used to smelt relatively small outputs (from 500 to several thousand tons of tin per year). Reverberatory furnaces have a higher MES. Large smelters tend to have more than one furnace. Refining of metal from high grade concentrates is accomplished by injecting air into the vat of molten tin.

While smelting and refining high grade ores is a relatively simple process, the treatment of low grade concentrates is both more costly and sophisticated. The simplest way to handle complex ores is to blend them with richer alluvial concentrates.[5] Smelting complex ores by themselves is more costly and more difficult. Because lode mines usually find it economical to ship concentrates still containing impurities, these must be eliminated by roasting or leaching the concentrates prior to smelting, by thermal or electrolytic refining of the smelted metal, or by a combination of both. The degree of pretreatment of concentrates and refining varies with the nature of the ore. Since each type of ore requires a specific treatment, and therefore particular equipment, smelters which handle low grade ores tend to specialize in the handling of particular types of concentrates. While the technology of alluvial smelting is widely available, smelting complex concentrates is an art, and it takes considerable time for new low grade smelters to reach full smelting efficiency.[6]

Table 4 lists the capacity, equipment, and cost of some recently-built smelters. The table shows the cost of building a tin smelter to be much lower than that of an efficiently-sized alumina refinery. Also apparent is the fact that low grade smelters designed to handle lode concentrates are three to four times more expensive to build than high grade smelters. Lastly, the table shows that recent entry has taken place at a variety of scales, and that scale is not a significant barrier to entry, at least in the case of high and medium-grade smelting.

In contrast to bauxite, which is 15 to 25% aluminum, tin concentrates are relatively high grade (40 to 77% metal) and high value (the price of tin is ten times that of aluminum). Transportation costs are therefore low.

[5]It is increasingly difficult to make use of this technique, as the governments of most countries producing alluvial concentrates prohibit their export.

[6]From interviews with A.R. Andrew, former Managing Director of Consolidated Tin Smelters, and P.A. Wright, extractive metallurgist, and from personal communication from S.C. Pearce, consulting metallurgist.

Concentrates can be economically shipped to smelters located far from the mines, and the market for tin concentrates is worldwide.

The potential for opportunistic exploitation in tin is therefore much lower than in bauxite, although it tends to be higher for lode than for alluvial tin. The equipment used in alluvial tin mining is mobile.[7] Alluvial concentrates can be transported over long distances, and smelted with minimum adjustment in any smelter. Entry into alluvial smelting is relatively easy, and can be effected at low scale and for less than U.S.$10 millions. Any mine can potentially choose among a number of smelters, or can integrate into smelting if desired. Similarly, the small scale of most alluvial undertakings makes the market for concentrates relatively competitive.

The dangers of being 'held up' are higher in the case of lode tin. Capital sunk in underground mines is less mobile. Because lode ores often contain impurities, their efficient smelting requires careful adjustment to the type of by-products they contain. This introduces an element of bilateral monopoly not found in the case of the purer alluvial concentrates.

Our survey of the tin industry has thus underlined major differences between tin and bauxite, and within the tin industry itself, between the mining and smelting of lode and alluvial ores. The contrast is greatest between aluminum and the alluvial sector of the tin industry. Compared to bauxite, alluvial tin is mined, concentrated, and smelted by relatively small scale methods and can be economically transported over long distances. Barriers to entry at both stages are low. As a result, we would expect trade in bauxite to be more susceptible to opportunism than that in alluvial tin concentrates and, consequently, vertical integration to be more prevalent in bauxite than in alluvial tin, a conclusion which is supported by the data.

The model also lead us to expect trade in low grade lode concentrates to incur greater disabilities than that for alluvial ones. The following section considers whether these considerations account for variations in vertical integration within the tin industry.

4.3. Explaining geographical differences in vertical integration within the tin industry

We have noted earlier that while the Bolivian tin industry has been vertically integrated, Thai, Malaysian, and Australian miners and smelters have organized their interdependance through spot prices set on the Penang market. The four smelters have therefore chosen to restrict themselves to the role of providers of a service. They have substantially integrated neither backward into mining nor forward into the manufacture of tin-containing

[7]Offshore dredges can be towed to new locations. Onshore dredges can be taken apart and re-erected. The same applies to gravel pumping plants.

products. In this section we argue that this geographical pattern can be explained by technical differences in the mining and smelting of lode and alluvial deposits. Let us first look at Malaysia, Thailand, and Australia, before turning to Bolivia.

Nearly all of the tin ore extracted in Thailand and Malaysia comes from alluvial deposits. Table 5 shows that in both countries the mining side of the industry is unconcentrated.[8] Because of low barriers to entry into alluvial mining, the market for tin concentrates in Malaysia and Thailand has been

Table 5

Structure of the tin mining industries in selected countries.

Mining Method	Number of companies	Number of units	Total output[a]	Output per company	Percent country output
Malaysia (1975)					
Gravel pumps	810	810	35,183	43	54.7
Dredges	30	55	20,331	678	31.7
Opencast		12	2,534		3.9
Underground	30[b]	30	1,893		2.9
Dulang	20,000[c]	20,000[c]	3,083		4.8
Other			1,340		2.1
Thailand (1976)					
Gravel pumps	244	244	8,166	33	39.9
Dredges		15	3,389		16.6
Suction boats	3,000[c]	3,000[c]	4,683	1.5	22.9
Dulang	4,500[c]	4,500[c]	1,020		5.0
Others		275	3,195		15.6
Bolivia (1913)					
Patino	1	2	16,005	16,005	35.9
Llallagua	1	1	5,771	5,771	12.9
Aramayo	1	6	3,673	3,673	8.2
Others	–	–	19,142	–	42.9
Bolivia (1981)					
Comibol	1	12	20,485	20,485	68.7
Medium mines	24	24	5,899	246	19.8
Small mines	964	964	3,417	3.5	11.5
Indonesia (1978)					
Gravel pumps	2	177	12,107		44.2
Dredges	3	35	13,568		49.5
Others			1,735		6.3

[a]Output in metric tones of tin-in-concentrates.
[b]Only one major company operating; balance refers to small operators.
[c]Approximately.

Source: International Tin Council, 1981; Thoburn, 1981, p. 41; Schurz, 1921; International Tin Council, 1982; Allen and Engel, 1979.

[8]The data of table 4 are in terms of companies. This, however, understates the degree of concentration in the dredging sector, as a large proportion of dredging firms have been under minority control and/or management of three major groups [Williamson (1974)].

competitive. The two colluding Malaysian smelters and Thaisarco thus seem to be in a monopsonistic position vis-à-vis the miners.

The strategic position of the smelters vis-à-vis Malay and Thai miners is not, however, as strong as it appears, as it is based on a governmental ban on the export of tin concentrates. Abuses by the smelters would most likely result in the lifting of such a ban. The high purity of Malaysian and Thai concentrates, and the location of the mines on or close to the coast would make it feasible for foreign smelters to compete for such ores.[9] Barriers to entry into alluvial smelting are also low, as shown by the establishment of two small smelters in Thailand soon after Thaisarco's smelting monopoly was abrogated. Similarly, it pays for Consolidated Gold Fields Australia (CGFA), which operates the large Renison mine, to keep sending its concentrates to the Penang smelters, since the latter are able to offer Renison competitive rates by mixing the mine's impure concentrates with those received from Malaysian mines. CGFA would build its own smelter if the charges became unreasonable. Ninety-eight percent of Bolivian tin production, on the other hand, comes from lodes exploited in underground mines. Bolivian tin mining has always been highly concentrated (table 5). Three factors are responsible for this high concentration. First, the lodes initially exploited in Bolivia were particularly rich. Patino's Uncia mine, and the Llallagua mine, which he later acquired, are the largest tin mines the world has ever known [Barton (1967, p. 218)]. Second, a significant investment is necessary to concentrate Bolivia's complex ores, and this constitutes a barrier to entry for small producers.[10] The magnitude of the investment and the relatively high level of technical expertise needed to efficiently separate the tin from its gangue benefitted at the outset the firms that were large enough to tap foreign sources of finance and hire skilled foreign engineers. The third reason for the high level of concentration in Bolivian tin mining has been the necessity for the early investors to build capital-intensive infrastructures. In contrast to Malaysia, where tin is mined close to the coast, most of the Bolivian tin mines are located in the Cordillera Real range of the Andes, at altitudes above 3400 meters (11,500 feet). Thee nearest harbor is more than 300 miles away over mountainous terrain. The first companies to mine Bolivian tin had to build roads or branch lines to connect with the main railroad line going to the coast. Those were large scale investments, which could only be undertaken by the largest firms.

Bolivia mines complex lode ores, from which tin is difficult to extract. As a result, more than half of the concentrates shipped from Bolivian mines are

[9]Smuggled concentrates from Malaysia and Thailand have been shipped to smelters in Spain and Brazil [Allen and Engel (1981, p. 54)].

[10]Patino's concentration plant at its Uncia mine installed sometime before 1905 was reported at the time to have cost $1 million [Klein (1965, p. 9)].

low grade and contain less than 40 percent tin.[11] Smelting Bolivian ores requires therefore, on average, more capital and skill than for alluvial ores. The equipment and the process used must be carefully adjusted to the characteristics of the concentrates. Such smelters experience a shakedown period before reaching full smelting efficiency. A potential smelter of Bolivian concentrates can therefore be expected to show a greater concern for guaranteed future supplies of ore than a smelter of alluvial ores; the up-front investment is larger, and the costs of switching to another input source significant.

5. Conclusion

The theory outlined in section 2 predicts that vertical integration will dominate trade in intermediate inputs when their market is characterized by both uncertainty and small number conditions. The pattern of vertical integration in aluminum and tin described in this paper is broadly consistent with these predictions. High MES and high capital requirements at both the bauxite mining and refining stages, high transportation costs in bauxite, and the need to tailor the refinery to the characteristics of the bauxite, have led to the almost total disappearance of arm's length bauxite transactions.

The alluvial sector of the tin industry offers the greatest contrast with aluminum. Mining alluvial ores is less capital intensive and of smaller scale than bauxite mining. The capital cost and the MES of smelting alluvial concentrates are low compared to bauxite refining. The market for such concentrates is worldwide because their transportation costs are low and their smelting can be undertaken without specific adjustments.

Lode ores are generally mined by larger-scale methods, are heterogeneous and costlier to transport, and must be smelted in larger, specialized plants. Their processing, as in the case of bauxites, requires subtle adjustment, locking mine and smelter into a more bilateral relationship. Not surprisingly, Bolivian tin, which is obtained from lode deposits, has almost always been integrated with smelting, whereas coordination by spot sale has, up to now, played a larger role in the alluvial tin industries of Malaysia, Australia, and Thailand. These differences in the extent of vertical integration are also consistent with the model.

Williamson's model of vertical integration assumes that firms will choose between spot market, contracts, and intrafirm coordination on efficiency grounds. The stronger the degree of competition, the more likely that efficient firms will prevail. On the other hand, inefficient firms may persist whenever competitive pressures are weak [Williamson (1985)]. In the last twenty years,

[11] Estimated from 1967 data in Fox (1970). In 1978, the average grade of Bolivian concentrates was 32 percent [Allen and Engel (1979, p. 86)].

state-owned companies have come to dominate tin mining in the major producing countries, and they have vertically integrated into smelting. These firms have privileged access to the public purse, and thus tend to be somewhat sheltered from the discipline of the market. As a result, they are able to engage in 'mistaken' integration. Transaction costs theory cannot explain such integration, but it predicts that it should result in inefficiencies for the reasons outlined in section 2.

An interesting case is that of Indonesia. Like Malaysia and Thailand, almost all of Indonesia's tin comes from alluvial deposits and is mined by a large number of relatively small mining units, dredges and gravel pumps (table 5). Vertical integration should therefore bring no particular advantage. Tin mining in Indonesia has always been a state monopoly, first of the Dutch, then of the Indonesian state, and national policies of self-sufficiency have led to vertical integration between mining and smelting.

Consistent with transaction costs theory, there is no indication that such integration has procured any efficiency advantages. Indeed Indonesia was, throughout the first half of the century, slower than Malaya in adopting modern mining and smelting methods. After independence, Indonesia's tin output was sent, for a while, to the nearby Malaysian smelters. Indonesia's desire to have its own smelter proved to be a costly proposition. The plant purchased in 1961 from a German contractor was technically flawed, and, after three years of trial runs, never produced more than a fifth of its design capacity. Consultants had to be brought in to make extensive alterations, and new furnaces had to be bought [Batubara and Mackey (1974)]. This illustrates the problem inherent in integrating into another stage of production: Indonesia's state mining enterprise, P.T. Timah, did not have the relevant knowledge to know it was being sold a basically unproved technology.

Today P.T. Timah smelts all of its mine output, but apparently at higher cost than the market alternative. In 1978, Indonesian smelting costs were twice as high as those charged by the Straits Trading Company in Malaysia [Thoburn (1981, p. 111, fn. 33)]. This cost difference is explained in part by the fact that, for public policy reasons, the smelter is required to employ three times as many workers than necessary, and must provide various other services to the nearby company town.[12] The Indonesian case thus supports the view that, whenever competitive pressures are weak, vertical integration may have to be explained by factors other than the minimization of transaction costs.

[12]Personal communication from S.C. Pearce, and Radetzki (1985, ch. 4).

References

Allen, H.W. and B. Engel, 1979, Tin production and investment (International Tin Council, London).

Ayub, M. and H. Hashimoto, 1985, The economics of tin mining in Bolivia (World Bank, Washington DC).

Bain, J., 1956, Barriers to new competition (Harvard University Press, Cambridge).

Baldwin, W.L., 1983, The world tin market (Duke University Press, Durham, NC).

Barton, D.B., 1967, A history of tin mining and smelting in Cornwall (D.B. Barton, Truro).

Batubara, K. and T.S. Mackey, 1974, Recent improvements in the rotary furnace smelting of Indonesian tin concentrates, in: Fourth world conference on tin, vol. 3, processing and smelting (International Tin Council and Government of Malaysia, Kuala Lumpur).

Brubaker, S., 1967, Trends in the world aluminum industry (Johns Hopkins, Baltimore, MD)

Fox, D., 1970, Tin and the Bolivian economy (Latin American Publications Fund, London).

Fox, W., 1974, Tin: The working of a commodity agreement (Mining Journal Books, London).

Goldberg, V. and J. Erickson, 1984, The law and economics of long term contracts: A case study of petroleum coke, mimeo.

Hashimoto, H., 1983, Bauxite processing in developing countries, in: Case studies on industrial processing of primary products, vol. 1 (The World Bank, Washington, DC).

Hennart, J.F., 1982, A theory of multinational enterprise (University of Michigan Press, Ann Arbor, MI).

International Tin Council, 1981, Tin statistics, 1970–1980, (International Tin Council, London).

International Tin Council, 1982, World tin mining (International Tin Council, London).

Joskow, P., 1985, Vertical integration and long-term contracts: The case of coal burning electric generating plants, Journal of Law, Economics and Organization 1, 33–80.

Klein, H., 1965, The creation of the Patino tin empire, Inter-American Economic Affairs 19, 2–23.

Klein, B., R. Crawford, and A. Alchian, 1978, Vertical integration, appropriable rents, and the competitive contracting process, Journal of Law and Economics 21, 297–326.

Macmillan, A., 1985, Annual review of the aluminum industry (Shearson Lehman, London).

Masten, S., 1984, The organization of production: Evidence from the aerospace industry, Journal of Law and Economics 27, 403–418.

The mineral industry . . . (McGraw Hill, New York).

Monteverde, K. and D. Teece, 1982, Supplier switching costs and vertical integration in the automobile industry, Bell Journal of Economics 13, 206–213.

Palay, T., 1984, Comparative institutional economics: The governance of rail-freight contracting, Journal of Legal Studies 13, 265–288.

Radetzki, M., 1985, State mineral enterprises (Resources for the Future, Washington, DC).

Rodrik, D., 1982, Managing resource dependency, World Development 10, 541–560.

Schurz, W.L., 1921, Bolivia: A commercial and industrial handbook (U.S. Department of Commerce, Special Agents Series no. 208. Washington, DC: U.S. GPO).

Stuckey, J., 1983, Vertical integration and joint ventures in the aluminum industry (Harvard University Press, Cambridge, MA).

Thoburn, J.T., 1977, Primary commodity exports and economic development (John Wiley and Sons, London).

Thoburn, J.T., 1981, Multinationals, mining and development: A study of the tin industry (Gower Publishing Co., London).

United Nations, Centre on transnational corporations, 1981, Transnational corporations in the bauxite/aluminum industry (United Nations, New York).

United States Bureau of Mines, Minerals yearbook.

Williamson, D.R., 1974, Tin shares – some of the problems of marketability and company structure examined, in: Fourth world conference on tin (International Tin Council and Government of Malaysia, Kuala Lumpur).

Williamson, O.E., 1971, The vertical integration of production: Market failures considerations, American Economic Review 61, 112–123.

Williamson, O.E., 1975, Markets and hierarchies (Free Press, New York).

Williamson, O.E., 1985, The economic institutions of capitalism (Free Press, New York).