

TRADE STRATEGY UNDER BILATERAL OLIGOPOLY : A CASE STUDY OF CHINA'S TUNGSTEN TRADE

By

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Introduction

Tungsten ores may be viewed as a typical primary product produced in the less developed countries (LDCs) and consumed by the developed countries (DCs) familiar with the adverse experiences of price and market instability known to other internationally-traded primary commodities. The ore is traded in a market approximating bilateral oligopoly, with China as a major producer. Although richly endowed with the ore, China does not appear to trade according to the inherent advantage of the endowment. To explain her trading behaviours is the starting point of this study.

This study of China's tungsten ore (referred to as tungsten) trade policy is a sequel to an earlier study of the world tungsten economy for the period 1960-1973 (Tan 1977). The present work extends the reference period to 1975. The findings suggest that Chinese tungsten trade strategy is serving two non-mutually exclusive objectives. Empirical results yielding an estimated backward sloping supply curve (i) support the hypothesis that tungsten exports are subject to foreign exchange requirements and (ii) show the limited sales of China as an expression of bargaining strength (through price leverage) by a dominant supplier in an oligopolistic international market.

After a brief discussion of the salient features of the tungsten world market, the empirical results explaining China's trading behaviour in this market are presented. The study highlights the problem of overcoming the foreign exchange constraint for China and for many developing countries having (a) a narrow range of exportables and (b) comparative advantage in a primary commodity but confronting international oligopolistic markets. Rules for optimal beha-

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viour under such market structures may run counter to trade specialization under comparative advantage. Barring domestic production bottlenecks, this means that rich factor endowments may not be fully utilized to provide urgently needed foreign exchange required by capital imports. The latter are essential for stimulating and accelerating the initial stages of development.

Characteristics of the Tungsten Market¹

Tungsten ores occur geologically as wolframite and scheelite. Because of its metallurgical properties, tungsten is used mainly in the production of high-speed steel, allied tool steels, tungsten-containing alloys and in tungsten-carbide tools and dies. This derived demand for tungsten as a vital element in the industrial economy leads to the close association of tungsten prices with business cycles.

The chief features of the tungsten market are the concentration of supply in a few developing countries (with the exception of the United States (US)); concentration of demand in the industrialized countries and the concentration of ore converters and/or traders. World trade in tungsten is conducted in a market approximating bilateral oligopoly where price formation is ultimately resolved by a test of bargaining strength (Cohen and Cyert 1965). The determinants are the short-run supply inelasticity, the state of the industrial countries consuming tungsten intermediates (in terms of their positions on the business cycles at any point in time) and the priorities of the socialist supplier-countries.

The influential role of China in the tungsten market stems from her endowment of the largest proven reserves of tungsten in the world. It is then a dominant supplier of high grade ores. But while tungsten is China's most important export metal (Weintraub 1974), her trading behaviour has not always been profit-maximizing. China's trade policy and priorities further complicate the price formation process in this market.

China's Trade in Tungsten

Table 1 shows the importance of Chinese supply of tungsten in the world market. Despite increased production during the period, Chinese tungsten exports (as a percentage of total production) has

¹ For a more detailed discussion see (Tan 1977).

TABLE 1

Production and Supply of Tungsten for Selected
Years, 1960-1975

		Thousand Tonnes Tungsten Content			
Year	Country	China	Rest-of-the-World	Total	
Production ^{a/}					
1960		10,800 (34.8)	20,000 (65.2)	31,200 (100.0)	
1965*		8,000 (29.4)	19,200 (70.6)	27,200 (100.0)	
1970		6,000 (18.2)	27,200 (81.8)	33,000 (100.0)	
1975		8,980 (23.8)	28,820 (76.2)	37,800 (100.0)	
Exports ^{b/}					
1960		9,752 (70.2)	4,140 (29.8)	13,892 (100.0)	
1965*		6,364 (51.7)	5,939 (48.3)	12,303 (100.0)	
1970		2,319 (11.6)	17,763 (88.4)	20,082 (100.0)	
1975		2,869 (11.6)	21,814 (88.4)	24,683 (100.0)	

Source: UNCTAD Quarterly Bulletin of Tungsten Statistics, Vol. IV No. 1, 1970; Vol. VIII No. 3, 1974; Vol. X No. 4, 1976.

Notes: ^{a/} Figures for China were estimated by the US Bureau of Mines.

^{b/} Measured by total imports from China and the Rest-of-the-World, respectively.

* Year when European (notably German, French and Swedish) and Japanese buyers shifted their purchases from Russia to China.

Figures in parentheses denote percentages of corresponding totals.

been steadily declining from 90.3 per cent in 1960 to 38.7 per cent in 1970, down to 32.0 per cent in 1975. China therefore appears to be curtailing its tungsten sales. The hypotheses put forth to account for the decline in Chinese sales in recent years are:

- (a) What appears as a 'high price strategy' hides production and supply shortages (Burrows 1971);
- (b) Instead of acting on short-run profit motive, China attempted to minimize the volume of tungsten sold, subject to some foreign exchange requirements;
- (c) China attempted to maximize profits by limiting sales;
- (d) China attempted to implement her "Fair Price" policy and other foreign trade tenets through price leverage achieved by limiting sales.

The reasons suggested to account for hypothesis (a) are the increases in domestic industrial consumption of tungsten and possible stockpiling of the material for military purposes.

The fact that the Chinese State Trading Corporations do not necessarily use the sole criterion of profitability explains hypothesis (b). Instead, tungsten is used as a residual foreign exchange earning export. The volume of tungsten ores sold depends on the foreign exchange requirements it is expected to cover. Two alternatives arise from this hypothesis:

- (1) Suppose there are n exportables (one of which is tungsten) available for covering the balance of payments deficit B . Let R_T be the export earnings of tungsten. Then, the volume of tungsten exported will be determined by the relative profitability of using it to cover the balance of trade gap. Tungsten will be sold to the point where:

$$MR_T/MR_i \geq MC_T/MC_i$$

for $i = 1, 2, \dots, n - 1$.

Subject to $R_t \leq b$, where:

MR_T	:	marginal revenues from tungsten exports
MC_T	:	marginal cost of tungsten production
MR_i	:	marginal revenue of the i th exportable
MC_i	:	marginal cost of the i th exportable

$$MR_T/MR_i = MC_T/MC_i$$

- (2) Suppose that tungsten is the only residual export available to cover the balance of payments gap B_t in period t (that is, supposing that export plans for all other goods cannot be changed). If R_t is the export earnings from tungsten in period t , then either

$$(a) R_t = B_t$$

or $(b) R_t \leq B_t$

Case (b) may result if, for example, expectations of future prices of tungsten are considered. However, whether China can take advantage of speculative price increases depends on its borrowing ability.

If hypothesis (b) holds, Chinese sales should be a decreasing function of tungsten price and her balance of payments, suggesting a backward sloping curve of Chinese supply. As Chinese balance of payments data are not available, estimates of export and import values are used as substitutes. Log-linearising, the Chinese supply equation appears as:

$$\ln CHS_t = f(\ln P_t, \ln (X_n/M)_t, \ln CHS_{t-1})$$

where	:	
CHS	:	Chinese supply
P	:	tungsten price
(x_n/m)	:	ratio of exports (net of tungsten exports) to imports in US dollars.

The lagged supply variable reflects the constraints on Chinese production capacity. The use of $(X_n/M)_t$ implicitly assumes a flexibility of the Chinese export policy for tungsten permitting instant maneuvering. The Chinese sale of tungsten is expected to be a decreasing function of the trade ratio. The better China's balance of trade, the less the foreign exchange gap to be covered by tungsten exports.

Hypothesis (c) is based on the relative importance of Chinese supply in the world market and the influence on tungsten prices China achieves by limiting supply. If China's objective is to maximize profits, the trade variable (X_n/M) forms no part of the explanation. The level of profits attainable depends on both the elasticity of

foreign demand (which is relatively inelastic in the short run) and the elasticity of Chinese supply (hence, on her production costs and export capacity).

Hypothesis (d) is based on the noneconomic objectives of foreign trade spelled out in a *Peking Review* article in 1959 (Liang 1959). Given the bilateral oligopolistic structure of the tungsten market and the alignment of all trading to prices compiled and quoted by the London biweekly *Metal Bulletin*,² the Chinese may view their limiting sales strategy as an expression of two policies: (a) their "policy of fair prices as opposed to the exchange of unequal values" and (b) their "policy to establish trade relations with all countries on the basis of equality and mutual benefits."³

In this study, hypotheses (b) and (c) were tested empirically as explanations of Chinese supply. Hypothesis (a) cannot be tested for lack of information on domestic consumption and stockpiling by China. Hypothesis (d) cannot be tested empirically either. Its consequences are not mutually exclusive with those of hypothesis (b).

Before discussing the empirical findings, the tungsten market during 1960-1964 will be discussed to illustrate the narrowness of the market and the effects of a particular sales strategy, on tungsten prices. This will facilitate better understanding of China's posture towards tungsten trading.

The Tungsten Economy During 1960-1964⁴

Figure 1 shows the behaviour of tungsten prices and Chinese supply for the period 1956-1975. Two factors explain the pre-1960

² The London *Metal Bulletin* (LMB) price quotations of a high and low price are based on reports by suppliers, traders and consumers of prices at which they have concluded transactions during the few days preceding the publication of the LMB.

³ That China is able to observe this principle stems from her State monopoly of foreign trade and her control of domestic prices. There have been examples therefore of China paying higher prices for imports and accepting lower prices for her exports. Mah Feng-hwa (1971) argues however that such instances have been only when the economic costs involved were not large."

⁴ This section draws heavily on Barbier (1971), to which the interested reader is referred for further details regarding the tungsten market during the second half of the sixties.

FIGURE I

Tungsten Price and Chinese Supply (Export),
1956-1975

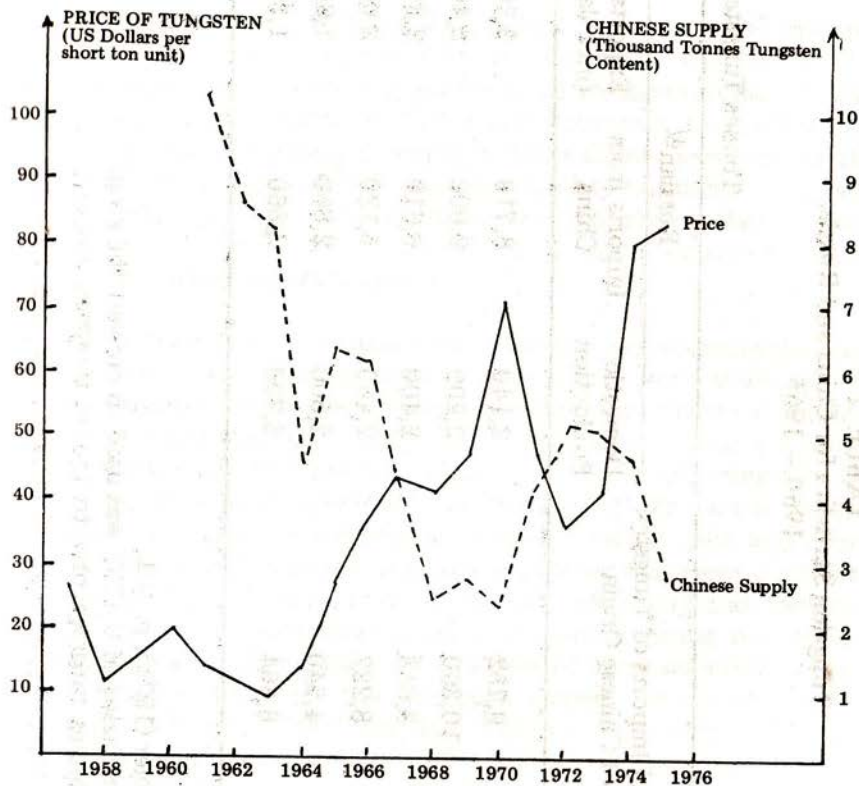


TABLE 2
Tungsten Statistics for China and Russia,
1960 - 1965

Year	World Imports of Tungsten of Chinese Origin	Russian ^{a/}			Tonnes Tungsten Content
		Domestic Production	Imports from China	Exports to West (incl. Japan)	
1960	9,752	2,140	8,710	2,200	
1961	10,360	2,200	9,000	2,400	
1962	8,648	2,400	6,610	2,300	
1963 ^{b/}	8,227	2,400	5,120	2,000	
1964 ^{c/}	4,540	2,500	2,860	1,600	
1965	6,364	2,700	2,860	1,550	

Notes:

^{a/}Source: Barbier (1971), p. 101.

The conversion factor of 0.4758 was used to convert the given statistics in tonnes tungsten ores to tonnes tungsten content.

^{b/}Year when China began direct trading of tungsten with the Western countries.

^{c/}Year when Chinese exports to Russia started to fall.

prices. In 1958, the US government stopped its subsidies to domestic producers of tungsten so, prices ceased to be supported artificially. In 1959 Russia entered the world tungsten market, thereby easing the existing tightness of availability in the western market. Tungsten prices therefore began to soften from 1958.

Between 1959 and 1964 Russia had large tungsten imports from China. These deliveries possibly represent repayments of Russian loans to China for her purchases of Russian products. Table 2 gives tungsten statistics for these two countries. Comparing the volumes of Russian tungsten imports (from China) and exports (to the West) during 1960-1965, and the quality differences in ores produced by the two countries, it has been concluded that Chinese ores (of better grade) were retained for Russian consumption and Russian ores were exported instead.

A strict preference for long-term contracts characterizes the Russian sales strategy. Because of her lower grade ores (which require wider tolerances for ore specifications used in these contracts) Russian sales were lower than the western price. Through this sales strategy Russia dominated the market, absorbing the world tungsten requirements to a large extent. Under 'normal' circumstances (where there is a relatively even spread in supply between long and short term contracts), the volume of purchases under long-term contracts were insufficient to prevent free interaction of supply and demand. But the long-term contracts closed with Russia during this period covered sizable volumes. This led to a loss of a considerable part of tungsten transactions for the European traders. The result was an apparent decline in global demand. Prices subsequently weakened because of market inelasticity and additional tonnages released in spot lots narrowed the market further. Assuming that the Chinese deliveries to Russia were based on London prices (their barter agreements probably being in value terms), the *raison d'être* for the Russian sales strategy is that she attempted to lower the London prices (by selling relatively smaller quantities in the market to those obtained from China) to depress the reference price and obtain larger tonnages of tungsten from China.

Other factors contributing to the weakening of prices during 1960-1964 were supplies from Czechoslovakia, Britain and China. Czechoslovakia began selling large quantities of ores probably acquired in previous years from Russia and China as part of some

barter agreements. The British government decided during the same period to release her government-held stocks (from the Korean War period) and China began her direct trading of tungsten with the West in 1963.

The crisis in tungsten prices during 1960-1964 led to the closure of many western mines. Only well-equipped and particularly high-grade mines, like those in Portugal and South Korea, maintained a reduced production. The Bolivian miners' call for a remedy led to the establishment of the UNCTAD Committee for Tungsten which convened its first conference in January 1963.⁵

By the end of 1964, the massive sales by USSR ceased, following the running out of Chinese supplies as a result of the Sino-Soviet rift. The Chinese continued to trade tungsten directly with the West, but adopted the alternative technique of limiting sales (and hence shorter-term supply contracts). It seems that the Chinese realized the damaging effects on bargaining strength, and therefore price, resulting from long-term supply contracts covering huge tonnages.

Empirical Findings⁶

All estimates of the Chinese supply equation are based on time series data for the period 1960-1975.⁷ Chinese supply is measured in physical units (thousand tonnes tungsten content). The price series are arithmetic averages of the high and low prices quoted by the London Metal Bulletin (LMB). These LMB prices quoted in

⁵ In 1975, 5 countries (Australia, Bolivia, Peru, Portugal and Thailand) formed the Tungsten Producers' Association. The potential effectiveness of this cartel is restricted by their small share of the world market (amounting to 21.4 per cent in 1973) and their unpredictable supply behaviour. None of these countries individually produces amounts sufficient for exerting a strong price leadership.

⁶ See Appendix 2 for regression results.

⁷ Data for Chinese supply and tungsten prices are obtained from the Quarterly Bulletin of Tungsten Statistics of the UNCTAD Committee for Tungsten; Chinese trade figures are from *Current Scene*; the industrial production indices for Japan, Western Europe and USA and the price indices required for deflating tungsten prices are extracted and/or compiled from various OECD publications and the US *Survey of Current Business*.

Pounds Sterling per tonne unit were converted into US Dollars per short ton unit in view of the sterling devaluation of November 1967 and the "on-off" exchange rate flotation in the subsequent period. To eliminate inflation in commodity prices, these prices were deflated by the US Wholesale Price Indices for Manufactures (1960=100) before use in the regression runs. Employing this deflator implies that China spends her tungsten export earnings largely on manufactured goods. Given the content of China's import bill, this is a realistic assumption.

Chinese supply had to be measured by data for imports of tungsten from China. The estimated Chinese supply equation based on hypothesis (b) gave an insignificant coefficient for the lagged supply variable. Removing the lagged supply variable resulted in improved estimates, with both price and trade variables negatively related to Chinese supply. To check that the negative price coefficient is not a consequence of simultaneous equation bias,⁸ the two-stage least squares estimation was applied. The instrumental variables used in the two-stage estimation were the industrial production indices for the US, Western Europe and Japan. The results confirm the negative relationship between price and Chinese supply, yielding a calculated long-run price elasticity of -1.0158. This value is consistent with the longer term planning process. If hypothesis (b) holds, the long-run price elasticity of supply should theoretically have the value of -1.

To test hypothesis (c), Chinese supply on price and lagged supply only were regressed. The trade variable is irrelevant here since foreign exchange requirements is no longer a restricting factor. Two-stage least squares estimation was employed (to eliminate simultaneous equation bias arising from use of price as an explanatory variable) with similar instrumental variables as before. Again an inverse relationship between price and Chinese supply was established. The regression estimate gave a calculated long-run price elasticity of -0.72 for Chinese supply. A positive correlation between supply and lagged supply variables was obtained but the estimate was insignificant at the 5 per cent level.

⁸In the model of the world tungsten economy, Chinese Supply and Price equations are two of nine equations for the model. Simultaneous equations' bias arise from the dynamic integration of these two equations. For further details, see (Tan 1977).

The estimation results give a backward sloping curve for Chinese supply. Although the trade balance variable failed to yield significant estimates, it is not rejected as an explanatory variable for the following reasons. First, a foreign exchange objective of tungsten sales refers to the balance of payment. This need not move parallel with the balance of visible trade. Second, Chinese visible trade values are compiled from trade statistics of the trading partners. This method contains the well-known fob-cif pitfall as well as many others relating to the origin-destination system of individual trade statistics and time lags. Third, Chinese tungsten export earnings (for determining the value of X_n) were estimated from the volume exported at annual average LMB price. That Chinese supply equation is a decreasing function of the price and trade balance variables may be interpreted as an expression of oligopolistic selling, subject to the balance of trade constraint. China's inability to exploit her comparative advantage in the tungsten trade has to be viewed against the stockholding behaviour of processed tungsten by the major consuming countries, the narrowness of the tungsten market, the profit-maximizing behaviour of the other (capitalistic) chief exporters of tungsten, the formation of the biweekly LMB quotations and the general alignment of tungsten trading to LMB quotations. With the bilateral oligopolistic structure of the tungsten market, the backward sloping supply curve therefore summarizes the bargaining strength and hence, price leverage China exerts by a limiting sales strategy.

Role of Tungsten in China's Foreign Trade Planning and Policy

The implementation of China's tungsten trade strategy can be better understood within the context of her economic and foreign trade planning and trade policy.

Discussions on national economic planning in China argue that Chinese planning is not taut (see Berger 1975, Paine 1976, Perkins 1968). It has some flexibility to allow for adjustments and modifications as the plan is being implemented. Under the Chinese economic system, such flexibility also pertains to the foreign trade sector.⁹

⁹ For a discussion of State Foreign Trade Corporations in China, see (Donnithorne 1967)

For a discussion of basic principles in foreign trade planning and objectives of foreign trade policy, see (Donnithorne 1967, Mah Feng-hwa 1971, Wang Yao-ting 1974, Wen Liang 1959).

Given this flexibility and her small foreign trade ratio,¹⁰ exports can always be maintained by reducing consumption in the short-run. In the light of some factors, namely:

- (a) this element of some flexibility in the system,
- (b) the ease with which tungsten can be mined by labour-intensive methods, the increase in domestic production of tungsten in recent years and the ease with which rare metals (of which tungsten is one) can be transported,¹¹
- (c) the slow growth in domestic steel production and the relatively huge amounts of tungsten not exported (between 1970 and 1975); Chinese annual retained tungsten output averaged 3688 tonnes tungsten-content. In comparison, the average annual tungsten consumption in steel-producing Japan for the same period was only 2750 tonnes tungsten-content), and
- (d) the sizable tungsten deposits in China¹² and the failure of capacity constraint (proxied by the lagged Chinese supply variable) to explain the Chinese tungsten sales,

the hypothesis of limiting sales to camouflage production bottlenecks and supply shortages appears untenable.

Since the mid-sixties when China began direct trading in tungsten, her tungsten export earnings as a proportion of total export earnings have been declining. Over the 1965-1975 decade, tungsten export earnings averaged only about 1 per cent of total export earnings. Some explanation is needed why China is not trading according to comparative advantage despite increased production, and why it is not utilizing the flexibility of her planning system and small trade ratio (which would permit shifting from domestic consumption to exports when advantageous to do so).

The determination of the level of China's foreign trade is known to follow from a material balancing process at the national level. Once the import requirements are identified, the exportables are

¹⁰ Dwight Perkins' estimate of this ratio for 1953-1957 lies in the range of 7-11 per cent while Liu Ta-Chung argues that it is closer to 10-15 per cent. For details, see (Perkins 1968).

¹¹ I am indebted to Mr. A.B. Ikonnikov for the last point.

¹² For details, see (Ikonnikov 1975), pp. 442-3 and 463-4.

then sought out to provide the foreign exchange requirement of the import bill. Given the declining share of tungsten in total Chinese export earnings since 1963 when she started direct trading in tungsten, and the margin allowed by the planners along with her planned approach to foreign trade, China's behaviour in the tungsten market may be seen in the following light. From the empirical findings presented, her tungsten trade strategy appears to be the outcome of some constrained optimizing procedure. The objective is to minimize tungsten price per sales subject to the (residual) tungsten export earnings meeting a specified foreign exchange requirement. Considering tungsten as a depletable resource might be a factor in the specification of the foreign exchange target required. The tungsten sales concluded at the bi-annual Canton Trade Fairs may then be viewed as the outcome of tâtonnement processes conducted at the Fairs where Chinese tungsten sales are usually negotiated at prices invariably higher than LMB quotations for parallel periods.

That Chinese trade strategies may have simultaneously fulfilled the noneconomic objectives included among her pronounced trade principles must be viewed against her centrally-controlled foreign trade and her options in the relevant markets. According to Wang Yao-ting, Chairman of the China Council for the Promotion of International Trade: "To ensure that foreign trade develops along the socialist road, China has consistently pursued a policy of controlling and protecting trade. A series of measures were adopted in foreign trade. . . (which) effectively. . . ensured that China's foreign trade was carried out in accordance with the established principle, policy and the economic plan." Specifically, our study illustrates an instance when the satisfaction of noneconomic objectives have complemented the objective of maximizing economic gains. The study however, generally emphasizes the constraint of foreign trade on the development options available to China. With her exports being largely agro- and extractive-industry based, the foreign trade sector of China is visibly a lagging as it is a balancing sector.¹³

Conclusion

This examination of Chinese behaviour in tungsten trading reiterates a fundamental problem for developing countries desiring increased trade for developmental finance. Under certain world

¹³For an exposition of Kindleberger's three roles of foreign trade for the national economy, see (Kindleberger 1962).

market structures, optimal trade strategies may call for a lower volume of exports. As this case study exemplifies, factor endowment itself is no prerequisite for maximal trade. Unless countries can diversify exports, the foreign exchange earnings attainable per period is constrained. Regrettably, export diversification itself is often one of the goals which the developmental finance requires. In the circumstances and without relying on borrowing and aid facilities, it follows that full advantage cannot be taken from the efficacy of intertemporal allocation of investment.

APPENDIX I

Data Used in Regression Analysis

Year	CHS	P	E _T	X	M	UWHP
1960	9.752	19.30	26.16	1,960	2,030	1.00
1961	10.360	15.36	22.11	1,530	1,495	1.00
1962	8.648	10.65	12.80	1,525	1,150	1.00
1963	8.227	8.79	10.05	1,570	1,200	1.00
1964	4.540	14.82	9.26	1,750	1,470	1.01
1965	6.364	26.10	23.08	2,035	1,845	1.01
1966	6.134	37.20	30.87	2,210	2,035	1.04
1967	3.779	43.85	23.03	1,945	1,950	1.05
1968	2.416	41.05	13.78	1,945	1,820	1.08
1969	2.786	46.63	18.05	2,030	1,830	1.12
1970	2.319	70.43	22.70	2,050	2,240	1.16
1971	3.958	49.52	27.24	2,415	2,305	1.20
1972	4.975	35.42	24.49	3,085	2,835	1.24
1973	5.062	40.32	28.36	4,895	4,975	1.33
1974	4.672	80.13	52.02	6,560	7,415	1.62
1975	2.869	83.28	33.20	6,845	7,245	1.81

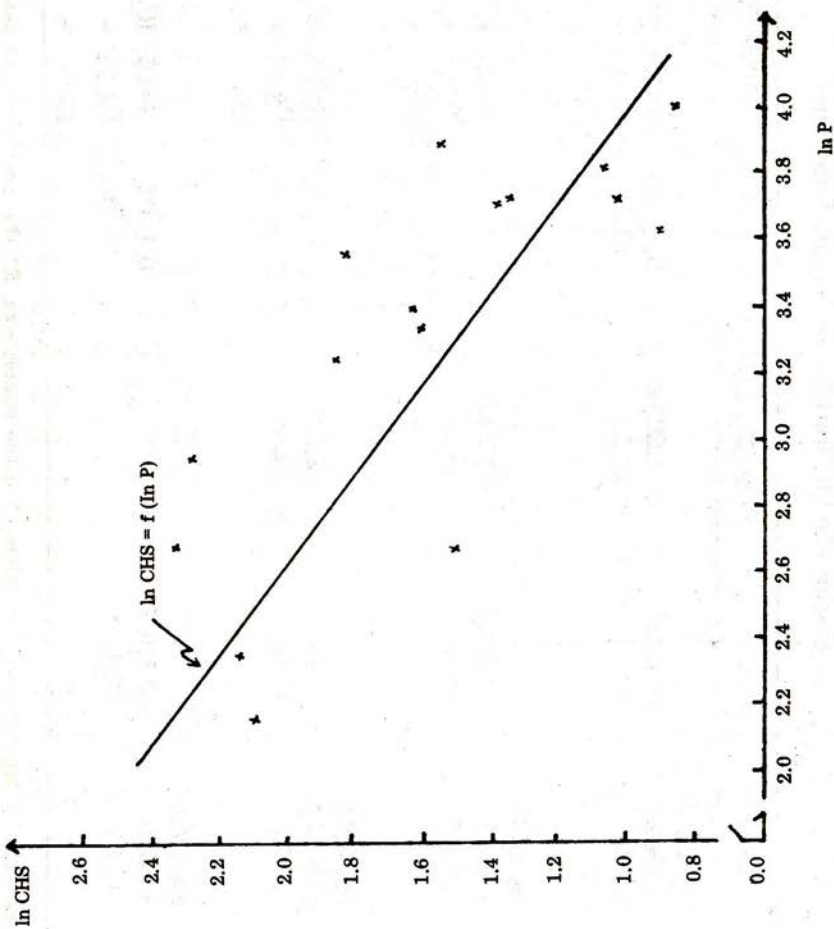
Notation	Variable	Unit of Measurement
CHS	Chinese Supply	Thousand Tonnes Tungsten Content
P	Tungsten Price	US Dollars Per Short Ton Unit
E _T	Chinese Tungsten Earnings	Million US Dollars
X	Chinese Total Exports	Million US Dollars
M	Chinese Total Imports	Million US Dollars
UWHP	US Wholesale Price Index for Manufactures	1960=100

APPENDIX 2

Regression Results for Chinese Supply Equation

	Constant	$\ln P_t$	$\ln (X_n/M)_t$	$\ln CHS_{t-1}$	Other Statistics
(1)	By TSLS 3.5062 (2.3)	-0.6781 (2.0)	-1.2672 (1.1)	0.2349 (0.9)	N=15; $R^2 = 0.6979$; F _{3,11} = 8.4710; DW = 1.3700;
(2)	By OLS 4.5147 (6.2)	-0.8662 (4.2)	-1.5626 (1.5)		N=15; $R^2 = 0.6636$; F _{2,12} = 11.8341; DW = 1.4276;
(3)	By TSLS 5.0473 (5.5)	-1.0158 (4.0)	-2.1922 (1.8)		N=15, $R^2 = 0.6516$; F _{3,11} = 11.2224; DW = 1.4544;
(4)	By TSLS 3.2579 (2.6)	-0.5967 (2.4)		0.1708 (0.6)	N=15; $R^2 = 0.6449$; F _{2,12} = 10.8945; DW = 1.4377;

Note: Values within parenthesis are + - values; N is the sample size, R^2 the coefficient of determination, F,



The following is a graph of the Price-Supply relationship based on regression equation (4) in Appendix 2.

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