Perverse Supply Response in the Liberian Mining Sector

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Abstract

Under neoclassical assumptions, and the usual *ceteris paribus* stipulations, a profit maximizing firm is expected to increase production in response to rising prices. These situations normally produce the rather well-known upward sloping supply curve for the firm which can usually be generalized to the industry. This paper examines whether these situations held for firms in the iron ore mining sector in Liberia between 1951 and 1985 under a system where royalties were levied on the per unit level of production and on the basis of the price of the ore. It investigates whether iron ore mining companies have an incentive to increase ore production when prices are low to attract lower total royalty payments under conditions where: (a) base-mining operations are

vertically integrated and firms employ transfer pricing between mining and upstream processing entities and (b) large quantities of ore can be shipped at relatively low prices and held in inventory either as ore or added-value products, such as steel, to take advantage of higher prices in the future. The paper specifies and estimates two simple linear supply models of the Liberian iron ore industry. It uses data for 1951–1985, the period for which the most consistent and reliable data exist prior to the start of the 14-year conflict in 1989. The analysis finds that the price coefficient estimates from both models are robust but negative and suggest that a perverse response in the supply behavior of mining companies in Liberia over the period 1951–1985 cannot be ruled out.

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I. Introduction and Background

The natural resources sectors and particularly the iron ore mining sub-sector are attracting increasing attention in post-conflict Liberia. The iron ore sub-sector has played a major role in attracting substantial foreign direct investment into the country and is expected to play a major role in spurring growth and employment in the medium to long term. The iron ore reserves in Liberia are estimated at just over 3 billion tons concentrated mostly in the western and north western parts of the country, although it is estimated that about 1 billion tons could be in the eastern part of the country in the Putu range (see Annex 1).

Early interest in Liberia's iron ore assets dates to the 1930s although prospecting in earnest did not take off until soon after World War II in response to the substantial reduction in domestic reserves in Europe and North America. In 1938, US Steel undertook a feasibility study for mining operations in Liberia. However, the absence of adequate port facilities made the venture financially unattractive. After the United States signed an Agreement with Liberia in 1943 for the construction of the Freeport of Monrovia, interest in iron ore mining resumed and in 1945 a mining concession for the Bomi Hills reserves was signed with Lansdell K. Christie. Subsequent concessions were concluded following the completion of the port in 1948.

According to Swindell (1967), one feature of the post-war iron ore industry was the concentration of production in large, highly-mechanized mines with a direct link with steel firms. This was also the case for most of the mines in Liberia and not surprisingly so, since the steel industry consumes 95 percent of all iron ore. Christie, who negotiated the concession in 1945, joined up with Republic Steel Corporation in 1949. The first concession in Putu was agreed in 1953 and operated by LAMCO, the Liberian American-Swedish Mineral Company, with 50 percent ownership held by the Liberian government. The opening of the mines in Nimba involved a joint venture with LAMCO and Bethlehem Steel. The mines in Bong were operated by DELIMCO, a co-operation between the Liberian government and steel mills from Germany. Swindell (1967) suggests that large mines and fixed, long-term contracts (10-15 years) were important for the viability of the mines and hence encouraged the close link between steel mills and mines. However, work by Rogers and Robertson (1987) suggests that while it is clear that long-term contracts played an important part in financing new mine development during the 1960s and 1970s, their subsequent role in this regard is more doubtful. They also conclude from their quantitative analysis that long-term contracts tend to promote market stability but may also hamper necessary orderly market adjustment.

The production of iron ore in Liberia has shown impressive growth since the start of mining in the early 1950s. Annual production increased from 180,000 metric tons in 1951 to peak at nearly 25 million metric tons in 1974. The production increases were particularly sharp after 1964 with the opening of the Bong Mines in 1965. However, with the onset of the oil crisis in

1973/74, production gradually fell to about 16 million tons in 1985. More current production data beyond 1985 are sparse and, with the subsequent onset of the civil war in 1989, production ceased altogether. As Figure 1 shows, exports have more or less mirrored production with little variance and most of the variance was observed just before and after the onset of the oil crisis in 1973/74. This suggests that mining companies were maintaining very little inventory of ore in Liberia. One possible reason for this is the fact that most of the mining is done during the dry season and maintaining stockpiles of iron ore into the wet season would greatly increase its moisture content and consequently increase shipping costs and lower the price.

Figure 1: Liberia, Production and Exports of Iron Ore (1951 – 1985)

Source: Author's calculation

Liberia's share of world iron ore production increased from about 0.6 percent in the 1960 to peak at about 3 percent in the 1970s before falling to 1.8 percent in 1985 (Table 1). Over the same period, its share of Africa's total production of iron ore increased from 21 percent to 48.4 percent, before falling to 28.9 percent in 1985. Between 1950 and 1985, the Africa region produced an average of about 6 percent of the world's iron ore production. The other major producers in the Africa region during the period were South Africa and Mauritania. Sierra Leone

and Guinea were also important producers in the West Africa region, while Algeria, Tunisia and Morocco were important producers in the North Africa region.

Table 1: World Iron Ore Production, 1950 -1985 (Mn. tons)

Country/Region	1950	1960	1970	1980	1985
North America	102.9	108.3	139.6	97.0	87.8
United States	99.6	88.8	91.3	70.7	48.8
Canada	3.3	19.5	48.3	26.3	39.0
Latin America	5.8	43.4	79.1	154.1	156.5
Brazil	2.0	9.3	30.0	114.7	120.0
Chile	3.0	6.0	11.3	8.6	5.8
Mexico	0.6	0.9	4.8	8.1	9.5
Peru	0.0	7.0	9.7	5.7	5.1
Venezuela	0.2	19.5	22.0	16.1	14.8
Other	0.0	0.7	1.3	0.9	1.3
Pacific Basin	7.6	24.9	90.4	143.9	144.8
Australia	2.4	4.4	51.1	95.5	95.3
India	3.0	10.7	31.4	40.7	42.5
Other	2.2	9.8	7.9	7.7	7.0
Africa	7.0	14.3	49.0	60.0	55.8
Liberia	0.0	3.0	23.7	18.2	16.1
Mauritania	0.0	0.0	9.1	8.6	9.2
South Africa	1.2	3.0	9.1	26.3	24.4
Other	5.8	8.3	7.1	6.9	6.1
Western Europe	74.2	138.5	121.1	69.8	43.7
EEC	58.5	111.6	82.2	32.7	16.4
Spain	2.1	5.6	7.1	9.9	6.7
Sweden	13.6	21.3	31.8	27.2	20.6
Unallocated	3.0	14.2	27.3	23.2	15.5
Eastern Bloc	49.5	173.4	256.5	339.0	392.3
USSR	44.0	106.0	195.5	250.0	248.0
Eastern Europe	3.5	9.3	10.0	6.0	6.3
China	2.0	55.0	43.0	75.0	71.0
North Korea	0.0	3.1	8.0	8.0	8.0
World Total	250.0	517.0	763.0	887.0	896.4
Liberia's share (%):					
Africa	0.0	21.0	48.4	30.3	28.9
World	0.0	0.6	3.1	2.1	1.8

Source: U.S. Bureau of Mines

Based on the level of world exports for 1985, Liberia was the largest exporter of iron ore in Africa and ranked 7th among world exporters of iron ore with 16.2 million tons of exports or about 4.3 percent of total exports in 1985. This compared with its peak share of 7 percent of global exports in the 1970s. In the 1970s, the largest portion of Liberia's exports (approximately 80 percent) were destined to the EEC with about 10 percent to Japan and about 8 percent to the United States. The structure of exports showed little change in the 1980s.

Table 2: Major Exporters of Iron Ore, 1950 – 1985 (Mn. Tons)

Country	1950	1960	1970	1980	1985
Brazil	0.9	5.4	27.9	79.0	92.3
Australia	0.0	0.0	44.5	80.4	88.3
USSR	3.2	15.4	34.9	46.9	45.0
Canada	2.0	17.3	39.3	39.0	32.2
India	0.6	8.8	18.8	26.2	28.8
Sweden	12.9	19.7	28.3	21.0	18.2
Liberia	0.0	3.1	22.6	17.4	16.2
South Africa	0.0	0.4	5.5	13.8	10.2
Mauritania	0.0	0.0	8.9	8.9	9.3
Venezuela	0.0	19.2	20.1	11.8	9.0
Peru	0.0	5.1	9.9	5.6	5.4
United States	2.6	5.2	5.3	5.8	5.0
Chile	2.6	5.2	10.1	7.8	4.8
France	7.6	27.2	18.7	8.7	4.6
Philippines	0.6	5.4	1.9	4.3	3.9
Norway	0.5	1.4	4.9	3.2	2.6
Other	12.1	19.9	19.6	13.8	3.0
Total	45.6	158.7	321.2	393.6	378.8

Source: US Bureau of Mines

Prices

According to Toweh (1989), iron ore is sold in a variety of types and grades on the world market. It is available as direct shipment lump ores, sinters, sinter feed (fines or concentrates used to manufacture sinter) and pellets. The price for iron ore is usually quoted on the basis of its iron (Fe) content on a dry basis. Such iron content of shipped ore could range from 52 to 68 percent.

Since the start of mining in Liberia in 1951, the nominal prices of iron ore have been relatively stable up to 1972. However, prices rose sharply following the onset of the first oil crisis in 1973/74. The sharp difference in the variability in prices between the two periods is seen from a comparison of the coefficient of variation of prices for the two periods. For example, the coefficient of variation for the first period (1951-1972) was 0.09 compared with 0.29 for the second period between 1973 and 1985. Overall, nominal prices have shown an upward trend over the entire period between 1951 and 1985. Real prices² have been much more variable than nominal prices over the first period (1951-1972), with a coefficient of variation of 0.13 compared with 0.09 for nominal prices. However, for the second period (1973-1985), there was much less variability in real prices (coefficients of variation for the real and nominal prices were respectively, 0.08 and 0.29). Overall, real prices for iron ore have shown a downward trend in contrast with the upward trend of nominal prices.

² Prices deflated by the US Consumer price index (1982-1984 =100)

Figure 2: Iron ore Prices (1951 – 1985)

Source: Author's calculation

Production Costs

Data on the production costs for iron ore for the period between 1951 and 1985 are scarce. However, 1984 estimated production costs of sinter feed for a selected group of countries including Liberia compiled by Toweh (1989) suggest that Liberia is a relatively high-cost producer of iron ore. Of the eight countries for which production cost data were available, Liberia had the 4th highest total cost of production (US\$16.96 per ton of sinter feed), after India, Sweden and Canada. Furthermore, the estimated total cost of production in Liberia was higher than the average of US\$16.27 for the selected group of countries (see Annex 2). In terms of the detailed operating costs, Liberia's labor, energy and raw material costs were higher than the average for the selected countries. However, Liberia's transport and handling costs were lower than the average for the group. Liberia also showed the third highest costs related to royalty and management fees.

A breakdown of the production costs showed that operating costs accounted for nearly 75 percent of the total cost while capital costs, royalty, taxes and management fees accounted for the remaining 25 percent of total cost. Of operating cost, the cost of raw material accounted for about 28 percent. Labor cost accounted for nearly 17 percent and energy cost accounted for 12

percent. In comparison, in South Africa, operating costs accounted for about 70 percent of total costs with capital costs, royalty, taxes and management fees accounting for the remaining 30 percent of total cost. The 1984 estimates also showed that capital cost as a share of total cost at 23.1 percent was double the share in Liberia at 11.4 percent.

Mining Sector and Fiscal Revenues

The mining sector has been and remains an important source of fiscal revenues in Liberia. The stream of fiscal revenues that flow from the iron ore assets is governed by the fiscal regime covering the sector and the specific concession agreements that the government negotiated with the mining companies. However, the primary stream of revenue includes the royalty revenues, the land rental payments, the import duties and the corporate income tax at the prevailing rate in the tax code or that the government has specifically negotiated with the investor. Since the end of the conflict in 2003, the government has signed Mining Development Agreements (MDAs) with four key iron ore companies and it is estimated that the companies will invest a total of US\$8.0 billion over the period of exploitation and create about 10,000 jobs. Investments comprise, among others, rehabilitation and installation of new mining plants, construction of railways, roads and bridges.

Given the importance of the mining sector to Liberia, policies for the sector need to be based on a thorough understanding of the entities operating in the sector. Such understanding should include sound knowledge on the price responsiveness of production and the implications for *ad valorem* royalties. Supply elasticities derived from supply response models indicate the speed and magnitude of production adjustment in response to changes in economic factors and hence they have important policy implications. To date, we are not aware of any published estimates of the responsiveness of Liberia's iron ore mining sector to changes in the international price of the commodity. This paper is therefore intended as a contribution to the knowledge gap.

The remainder of the paper is organized as follows. Section II provides a brief overview of the theoretical framework for the firm and industry supply response. Section III reviews the empirical literature. Section IV details the econometric analysis including the specification of the models as well as the estimation procedures and the results. Section V of the paper concludes with some policy implications.

II. Theoretical Overview

The theory of supply, within the framework of the theory of the firm in production economics, is well developed. The theory suggest that if factor prices (labor, electricity etc.) are known and profit-maximizing behavior is assumed, a firm's supply curve can be derived from its production function. Further, the industry supply function is simply an aggregation of the individual firms' production functions. The individual firm's production function may be expressed as:

$$Q = f(X_1, X_2, X_3, \dots, X_n)$$

where Q is the quantity of output

X_1 to X_n are quantities of variable and fixed factors of production (labor, land, capital, electricity, etc.).

The firm's technological set includes all the technical knowledge available at a particular point in time about the combinations of inputs necessary for the production of its output. The process of discovery may result in new and more efficient combinations of inputs. As these combinations become available to the firm, its technological set changes. This constitutes technological change.

The supply curve for an individual firm under perfect competition is defined as the firm's marginal cost curve above average cost in the short run. The firm's long-run supply curve would be the portion of its long-run marginal cost curve for which marginal cost exceeds average cost. Fixed factors of production form the basis of the distinction between short run and long run. When fixed factors are present and the firm is operating in the range where marginal cost equals marginal revenue, the firm is said to be in a short-run equilibrium. In the short run, the firm will remain in business as long as it is able to cover its variable cost. Consequently, the marginal cost curve above the average cost is considered to be the supply function for the firm. The horizontal aggregation of the individual firms' supply functions gives the industry's supply function. Some economists, Lee and Keen (2003), for example, have argued that the conditions for consistent and representational aggregation of the supply curves may not hold if the production functions underlying the various firms' supply curves are different and the input prices for the same factor input are different. However, such situations are more likely to arise in more complex industries where the range of technologies is much wider than in simple industries like mining where the range of technology is narrower.

The downward-sloping or perverse supply curve is less well-known and discussed in the theoretical literature. One theoretically intuitive example comes from the livestock industry. Since female calves can either be maintained for consumption or kept as part of the breeding stock, ranchers must regularly make the related decisions. If the price of beef is rising, rational profit-maximizing ranchers may take the decision to retain more female calves to expand the breeding stock and supply less for consumption. If this is replicated across the beef industry, in the short run, the supply of beef could be falling even as the price of beef is increasing. For an example, see Jarvis (1974). It has also been argued that risk and uncertainty may result in a negatively-sloped supply curve that violates the neoclassical assumptions of the law of supply. In fact, Just and Zilberman (1986) have drawn on data on rice risk in the Philippines reported by

Roumasset (1976) to show that the “law of supply” may fail under conditions of uncertainty even where producers have low levels of risk aversion.

III. Empirical Literature

Ultimately, the degree of supply responsiveness is an empirical question. The empirical literature on supply response in the mining sector is very sparse. Following a thorough, though not exhaustive search, we were able to find only one empirical study focused on estimating the short- and long-run price elasticities of supply for iron ore. Williams and Frazer (1985) used a log linear model with a Nerlove stock adjustment mechanism to estimate both short- and long-run iron ore price elasticity of supply for Western Australia. Their model utilized time-series production and price data covering the period from 1961/62 to 1981/82 and was estimated using Ordinary Least Squares (OLS) techniques. They found that supply was inelastic (0.61) in the short run but quite elastic (4.36) in the long run. Their estimate of the speed of adjustment from desired supply to actual supply implied from the coefficient of lagged output was 0.86. This suggests that more than three-quarters of the gap between desired and actual production was closed each year.

Similar supply response studies of other mining products making use of the partial adjustment mechanism have also been popular in the literature. For example, Owen (1980) used a partial adjustment framework and applied least squares techniques to time-series data for 1960-1978 to obtain estimates of short- and long-run price elasticity of supply of 0.15 and 0.71, respectively, for US uranium. He also obtained an estimate for the speed of adjustment from desired supply and actual supply of 21 percent. This suggests that less than one-quarter of the gap between desired and actual production was closed each year.

However, some economists have argued that the partial adjustment framework and the adaptive expectations framework, particularly where they are based on price-only models, may not be appropriate for estimating the price elasticity of supply for commodities. For example, Lecraw (1979) suggests that the partial adjustment adaptive expectations model may not be useful where bottlenecks prevent actual change in output from being equal to desired change and the price expectations have not been realized. Hojman (1980, 1984) also argues against the use of price-only Koyck-Nerlove models of demand and supply in non-ferrous metals. He argues that these models are incomplete specifications of demand and supply and suggest that the respective estimates of the price impact and the gap between long- and short-term effects are both biased. Furthermore, he suggests that for non-ferrous metals, a more realistic approach should look at least to the influence of general industrial activity, prices and substitutes, and production costs.

IV. Econometric Analysis

The Data

The data for the estimation procedures used in this paper cover the period from 1951 to 1985. The choice of the period is based on the fact that this period represents that for which we have the most reliable production data prior to the start of the 14-year conflict in 1989.

Econometric Models and Estimation Techniques

In estimating the supply response for iron ore in Liberia, we adopted two approaches. The first involved the traditional approach utilizing the price-only model in the context of the Nerlove partial adjustment mechanism. The second approach follows more closely that used by Hojman (1984), which includes a wider array of independent variables. Both approaches are discussed below.

Partial Adjustment Model

The partial adjustment model we use for the estimation of supply response relies on two principal behavioral assumptions. First, we assume that firms, the basic unit of the industry, plan for a level of output of iron ore in period t that maximizes profit (π) subject to prevailing conditions including cost. Functionally, this can be expressed as:

$$\pi_t = P_t Q_t^* - C(Q_t^*) \quad (1)$$

Where: P_t = price of iron ore in period t ,
 Q_t^* = the planned output in period t and
 $C(Q_t^*)$ = cost function

Further, we assume that price is exogenously determined under competitive market conditions. This is an assumption that may be more open to question since the world market for iron ore is quite complex and for a part of the period covered a substantial proportion of the iron ore trade was on the basis of long-term contracts. In addition, since many of the mines in Liberia had direct links to steel mills, it would be reasonable to assume that a substantial amount of the supplies from Liberia were valued at internal 'transfer' prices. However, there was still a considerable amount of iron ore that was traded on the 'free' market and in many cases contract prices were based on these free market prices (see, for example, Williams and Fraser, 1985) and contracts were often adjusted to reflect changes in 'free' market prices.

Following Williams and Fraser (1985), we specify the following exponential form for the cost function:

$$C(Q_t^*) = a \cdot Q_t^{*b} \quad (2)$$

Where: $b > 1$.

Substituting Equation 2 into Equation 1 we get:

$$\pi_t = P_t Q_t^* - a \cdot Q_t^{*b} \quad (3)$$

Taking the first differential with respect to Q_t^* we have:

$$d\pi_t/dQ_t^* = P_t - a \cdot b Q_t^{*b-1} \quad (4)$$

Setting $d\pi_t/dQ_t^* = 0$, we have the first order condition for profit maximization given by:

$$P_t = a \cdot b Q_t^{*b-1} \quad (5)$$

We can express Equation 5 in a linear form by taking logarithms and making the planned level of output Q_t^* the subject of interest:

$$\log Q_t^* = (-\log a \cdot b + \log P_t)/(b-1) \quad (6)$$

For simplicity we can rewrite Equation 6 as:

$$\log Q_t^* = b_0 + b_1 \log P_t \quad (7)$$

where: $b_0 = (-\log a \cdot b)/(b-1)$ and

$$b_1 = 1/(b-1).$$

The second behavioral assumption that we rely on for the model is that the adjustment from actual output to planned output does not take place instantaneously but is gradual, reflecting changes in the production environment including technology. We represent this gradual adjustment process using a technique that was developed by Nerlove (1958). The adjustment process is represented by the following equation:

$$Q_t = Q_{t-1} + \beta(Q_t^* - Q_{t-1}) \quad (8)$$

Taking logarithms in Equation 8 we have:

$$\log Q_t = \log Q_{t-1} + \beta \log Q_t^* - \beta \log Q_{t-1} \quad (9)$$

Since Q_t^* is not observable, we substitute Equation 7 into Equation 9 to get an equation in which all the variables are observable:

$$\log Q_t = \beta b_0 + \beta b_1 \log P_t + (1-\beta) \log Q_{t-1} \quad (10)$$

Finally, to arrive at the linear stochastic model to be estimated we add a disturbance term ε_t which we assume to be a random real variable which is well behaved in the sense that it has a normal distribution, is independent of the explanatory variables, has a constant variance and a mean of zero. The final model to be estimated is therefore presented as:

$$\log Q_t = \beta b_0 + \beta b_1 \log P_t + (1-\beta) \log Q_{t-1} + \varepsilon_t \quad (11)$$

where: $0 < \beta < 1$.

The model suggests that the output of iron ore in any particular period is determined by the price of iron ore and partly by the level of output in the previous period.

Since the model is expressed in logarithms, the coefficient βb_1 can be interpreted as the short-run price elasticity of supply. The long-run price elasticity of supply b_1 can be calculated from:

$$b_1 = \beta b_1 / (1 - (1 - \beta)) \quad (12)$$

The use of Ordinary Least Squares (OLS) estimation procedures to estimate the coefficients of the model presumes that the time series of price and production data are stationary, that is, do not have unit root. Granger and Newbold (1974), for example, have argued that when the stochastic process is non-stationary, the use of OLS can produce 'spurious regressions' with high R^2 values, high t-ratios but without economic meaning. Before we estimated the final model, we tested for unit root in the time series of the production and price data. Operating on the basis of the null hypothesis that the series contain a unit root, we employ three model variations of the popular augmented Dickey-Fuller (1979) test (See Annex 3 for details).

For the models we used in testing for unit root, the augmented Dickey-Fuller statistics were, respectively, -1.208, -1.522 and -0.180, all in the acceptance region at 1%, 5% and 10% levels of significance, respectively. We therefore cannot reject the null hypothesis for the presence of unit root in the iron ore production series.

In the case of the price series, for similar models as we used in testing for unit root, the augmented Dickey-Fuller test statistics were, respectively, -1.021, 0.426 and 1.180 (Annex 3) all in the acceptance region at 1%, 5% and 10%. We therefore also cannot reject the presence of unit root in the iron ore price series.

Having ruled out stationarity in both series, we also test for cointegration, that is, whether some linear combination of the production and price series is stationary. By definition X_t and Y_t are said to be cointegrated if there exists a parameter α such that $U_t = Y_t - \alpha X_t$ is a stationary process. To test for cointegration in the production and price series we employ the popular Johansen (1991) test with trace. The results of this diagnostic test are displayed in annex1. The

results suggest that we cannot reject the null hypothesis of no cointegration of the two non-stationary series.

Since we cannot rule out the presence of unit root in the production and price series, and we confirm from the Johansen test that the two series are not co-integrated we employed first differencing as a possible solution as suggested by Granger and Newbold (1974) to the problem of unit root.

Econometric Results

Using the method of Ordinary Least Squares on the first difference of the time series we estimated the following model for the supply of iron ore in Liberia (figures in parenthesis are t-statistics):

$$\text{Log } Q_t = 0.08 - 0.87 \log P_t + 0.28 \log Q_{t-1} \quad (13)$$

(2.44) (2.02) (3.30)

$$R^2 = 0.33 \quad F = 7.31$$

Based on both the Durbin's h test³ and the Breusch-Godfrey tests (Table 3), we cannot reject the null hypothesis (H0) of no serial correlation since the p-values of both test exceed the standard significance level of 0.05. In addition, the mean Variance Inflation Factor (VIF) for the model is 1.0 indicating that multi-collinearity is not a problem.

Table 3: Results of Tests for Serial Correlation in the Model

Durbin's alternative test for autocorrelation

lags(p)	chi2	df	Prob > chi2
1	0.438	1	0.5081

H0: no serial correlation

Breusch-Godfrey LM test for autocorrelation

lags(p)	chi2	df	Prob > chi2
1	0.491	1	0.4835

H0: no serial correlation

All the coefficients of the model are significant at the 5 percent level. The residuals from the estimated equation follow a near normal pattern as observed from the kernel density estimate and the standardized normal probability compared with the normal plots (Annex 4).

³ The Durbin h test is the relevant test since the model contains a lagged dependent variable.

Given that the model was specified in logs, $\beta b_1 = -0.87$ is the short-run elasticity of supply. We can use Equation 9 $\{b_1 = \beta b_1 / 1 - (1 - \beta)\}$ to get an estimate for b_1 , the long-run elasticity of supply, as follows:

$$b_1 = -0.87 / (1 - 0.28) \quad (14)$$

Therefore $b_1 = -1.21$.

Alternative Approach Model

For the alternative approach to estimating the supply response, we specify a model similar to that of Hojman (1984) as follows:

$$Q_t = A + \alpha_1 P_t + \alpha_2 Q_{t-1} + \alpha_3 P_{o_t} + \alpha_4 P_{s_t} + \alpha_5 I_t \quad (15)$$

Where:

- Q_t = output of iron ore in period t
- P_{t-1} = price of iron ore in period t-1,
- Q_{t-1} = the output of iron ore in period t-1
- P_{o_t} = price of oil in period t
- P_{s_t} = price of steel in period t
- I_t = US industrial activities

Unlike Hojman (1984), we do not specify substitutes for iron ore in our model. The primary reason for this is that we do not believe, *a priori*, that there were any economic substitutes for iron or steel during the period covered by the model. The trade in scrap metal was still relatively nascent and little progress has been made to date is using aluminum to replace steel, the product for which 95 percent of iron ore is used. In fact, Kelkar, Roth and Clark (2001) suggest that “although the use of aluminum in cars has been increasing for the past two decades, progress has been limited in developing aluminum auto bodies.” The substitution of aluminum for steel has been largely driven by regulatory pressure to meet fuel and recycling standards. However, Kelkar, Roth and Clark (2001) analyzed the cost of fabrication assembly of four different aluminum car body designs using current aluminum prices and fabrication technology. In the comparison with the conventional steel design, they conclude that “aluminum still has to overcome significant technological and economic hurdles before it can replace steel in the car body.”

Given that the price of oil (a major cost factor), the price of steel and the level of industrial activities (proxied by the US industrial production index) are also possible planning variables, we experimented with different lengths of lags of up to 10 years for these three variables, to see which gives the best fit for the overall model.

As Hojman (1984) rightly pointed out, this specification of the model is likely to face problems of multicollinearity of the right-hand-side variables. In our case, a simple correlation test shows that the prices of iron ore, steel and oil are all correlated to a fairly high degree. The US industrial production index is also correlated with the prices of iron ore, steel and oil.

Econometric Results

We used Ordinary Least Squares to estimate several equations in levels of which we present four (Table 4) for discussion. Equations 1 and 2 include all the regressors, including the prices of steel and oil with 5-year lags (possibly reflecting the planning horizon of mining investors). The only difference between Equations 1 and 2 is that Equation 2 has iron ore price lagged one period, reflecting a naïve price expectation. The model represented by Equation 2 is obviously a better fit of the data given the higher R^2 and F statistics. However, the mean Variance Inflation Factor (VIF) suggests that multi-collinearity could be a serious issue⁴. To address this issue, we re-estimated Equation 2 after dropping the variable with the lowest levels of significance, the US Industrial Production Index. The results presented in Equation 3 shows an improvement in the F statistics and the mean VIF dropped to 23.11 but still above the threshold of 10. The final equation (4) is estimated after dropping the oil price variable. This equation explains 97 percent of the variation in the production of iron ore in Liberia between 1951 and 1985. There is no issue with serial correlation and multi-collinearity between the independent variables does not appear to be a serious issue.

If we accept Equation 4 as the best fit for the data, it suggests that the short-run elasticity of supply is -0.84 with significance at the 99 percent level.

Table 4: Result of Regressions for the Alternative Approach

Regressors	Equation 1	Equation 2	Equation 3	Equation 4
Lagged dependent variable	0.65*** (5.32)	0.55*** (4.62)	0.74*** (12.93)	0.84*** (20.66)
Constant term	-1.48 (-1.26)	-1.81 (-1.70)	-0.16 (-0.29)	0.95** (2.95)
Iron ore price	-0.75** (-3.93)	-1.10*** (-4.91)	-0.89*** (-4.48)	-0.84** (3.91)
Oil price	-0.33 (-1.94)	-0.42* (-2.70)	-0.37* (2.35)	
Steel price	1.12* (2.97)	1.64*** (4.27)	1.60*** (4.01)	0.81** (3.48)
US Industrial Production Index	0.63 (1.38)	0.72 (1.77)		
Adjusted R^2	0.97	0.98	0.98	0.97
Durbin h p-Value	0.21	0.19	0.28	0.12
Breusch-Godfrey p-value	0.16	0.15	0.24	0.11
F Statistics	223.07	273.19	313.90	355.17
Mean VIF	25.67	29.56	23.11	9.08

Note VIF = Variance Inflation Factor. The t statistics in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

⁴ The Variance Inflation Factor (VIF) is a fairly widely used measure of the level of multi-collinearity and a common rule of thumb is that VIF above 10 points to serious issues with multi-collinearity.

V. Conclusion and Implications for Policy

We have estimated both the short-run and long-run price elasticity of supply of iron ore in Liberia over the period from 1951 to 1985 using the traditional partial-adjustment model and an alternative approach. With the partial-adjustment model, the estimates of price elasticity for the short and long run are both negative, indicating a perverse response by iron ore producers. The short-run elasticity of supply suggests that a 10 percent increase in price, other things remaining the same, would result in an 8.7 percent reduction in supply. The long-term elasticity of supply was -1.21, suggesting a larger response in the long term. The alternative approach produced an estimate of price elasticity that was also negative (-0.84) and close to that from the partial-adjustment approach. The analysis suggests that we cannot rule out a perverse response in the supply behavior of mining companies in Liberia over the period 1951 -1985. The fiscal policy implication of these estimates is that revenue projections from the mining sector based on a hypothesis of a positive supply response in periods of rising prices may have resulted in consistent overestimation of revenues with possible adverse impact on the fiscal balance.

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Annex 1: Liberia-Estimated Reserves of Iron Ore in 2004

Deposit	Location	Duration of prior mining	company	Type of ore	Reserves (million metric tons)	Ore grade (% Fe)
Mt. Nimba	Yekepa, about 340 kilometers east-northeast of Monrovia	1963-1983	Liberian American-Swedish Minerals Co., Joint Venture Operating Co. (LAMCO)	Hematitic itabirite	417	65-69
Do.	do.	Jan-Mar 1990	Iron Mining Co. of Liberia (LIMINCO)	do.	417	65-69
Mt. Nimba Western Area	do.	1963-1983	Liberian American-Swedish Minerals Co., Joint Venture Operating Co. (LAMCO)	Magnetitic itabirite	NA	52
Do	do.	Jan-Mar 1990	Iron Mining Co. of Liberia (LIMINCO)	do.	NA	52
Bomi Hills	80 kilometers northwest of Monrovia	1951-1977	Liberian Mining Co. Ltd	Magnetite	45	68
Mano River	Mano River Hills, near Sierra Leone border	1958-1983	National Iron Ore Co. Ltd	Limonitic	136	51
Bong Mine	80 kilometers northeast of Monrovia	1965-1990	Bong Mining Co.	Magnetite	290	35-45
Putu Range	Grand Gedeh County, 270 kilometers east-southeast of Monrovia	Undeveloped	do.	Itabirite	455	45
Bea Mountain	Grand Cape Mount County	Undeveloped	Liberian Mining Co. Ltd	Magnetite, hematite and goethite	382	35-45
Wologizi Range	Lofa County	Undeveloped	Liberian Iron ore and Steel Co.	Hematite	1,000	35-40
Goe Fantro	60 kilometers northeast of Monrovia	Undeveloped	Liberian American-Swedish Minerals Co., Joint Venture Operating Co. (LAMCO)/ Iron Mining Co. of Liberia (LIMINCO)	do.	NA.	35-40

Source: US Geological Survey Minerals Yearbook-2004

Annex 2: Estimated Sinter Feed Production Costs, 1984 (64% Fe, \$/tonne)

Cost Item	Liberia	Australia	Brazil	Canada	India	South Africa	Sweden	Venezuela	Average
Labor	2.84	2.47	0.82	4.34	1.01	1.36	4.00	2.86	2.46
Energy	2.00	0.54	1.20	1.72	1.48	1.18	3.25	0.62	1.50
Raw Material	4.82	3.67	3.70	4.79	4.50	4.58	4.91	4.39	4.42
Transport and handling	3.00	3.49	4.21	2.95	5.21	3.53	2.40	3.35	3.52
Total operating costs	12.66	10.17	9.93	13.80	13.80	10.65	14.56	11.22	12.10
Capital Costs	1.93	1.54	2.81	1.72	1.04	3.59	2.40	1.00	2.00
Royalty and management fee	2.01	1.42	0.84	1.63	4.03	0.56	0.64	2.82	1.74
Taxes	0.36	0.95	0.56	0.00	0.00	0.56	0.96	0.00	0.42
Total Cost	16.96	14.08	14.14	17.15	18.87	15.36	18.56	15.04	16.27

Source: Toweh, Solomon Hartley. (1989) and author's own calculations

Annex 2b: Share of Operating Cost

Cost Item	Liberia	% Share of operating cost	% Share of total cost
Labor	2.84	22.4%	16.7%
Energy	2.00	15.8%	11.8%
Raw Material	4.82	38.1%	28.4%
Transport and handling	3.00	23.7%	17.7%
Total operating costs	12.66	100.0%	74.6%
Capital Costs	1.93		11.4%
Royalty and management fee	2.01		11.9%
Taxes	0.36		2.1%
Total Cost	16.96		100.0%
South Africa			
Labor	1.36	12.8%	8.9%
Energy	1.18	11.1%	7.7%
Raw Material	4.58	43.0%	29.9%
Transport and handling	3.53	33.1%	23.1%
Total operating costs	10.65	100.0%	69.6%
Capital Costs	3.53		23.1%
Royalty and management fee	0.56		3.7%
Taxes	0.56		3.7%
Total Cost	15.30		100.0%

Source: Authors Calculations from Annex 2

Annex 3: Test for Unit Root and Co-integration in Production and Price Series

To determine with the iron ore production and price series were stationary we employed the following three model variations of the popular augmented Dickey-Fuller (1979) test:

1. Model with intercept and trend;
2. Model with intercept but no trend;
3. Model with neither intercept nor trend.

The results of the test for the three models are summarized in the table below for three levels of significance.

Results for Augmented Dickey-Fuller Test for Unit Root in Production Data Series

Model	Test statistics for Data Series		Critical Values		
	Production	Price	1%	5%	10%
Intercept & Trend	-1.208	-1.021	-4.306	-3.568	-3.221
Intercept, no Trend	-1.522	0.426	-3.696	-2.978	-2.620
No Intercept, No Trend	-0.180	1.800	-2.647	-1.950	-1.603

We also test for co-integration of the production and price series using the Johansen test. The results of the test are given in the table below:

Johansen tests for cointegration					
Trend: constant			Number of obs =		30
Sample: 1956 - 1985			Lags =		5
				5%	
maximum				trace	critical
rank	parms	LL	eigenvalue	statistic	value
0	18	-297.0186	.	10.7247*	15.41
1	21	-291.67458	0.29972	0.0366	3.76
2	22	-291.65626	0.00122		

Since the null hypothesis (H_0) for the Johansen test for co-integration is no co-integration (that is $r=0$) and since the value of the trace statistics is less than the critical value we cannot reject the null hypothesis of no cointegration.

Annex 4: Kernel Density Estimate and standardized normal probability compared with the normal plots