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Metal supply by state mines in LDCs and transition economies

by Stefano Mainardi

The analysis of the supply behaviour of mining companies has relevant theoretical and policy implications. Supply determinants can be identified in, among other elements, the ownership and control pattern and geological characteristics of mineral deposits. These factors can influence the production objectives of the mines, and their ability to achieve these objectives. Following a review of current literature hypotheses and a formulation of an interpretative framework, an econometric analysis is applied to mainly state mine-related data over the period 1984–94, relative to four geologically associated metals produced in developing and transition economies.

Stefano Mainardi, Associate Professor, University of Natal, Dept. of Economics, Private Bag X01, 3209 Pietermaritzburg, South Africa, e-mail: mainardi@econ.unp.ac.za, fax: +27-331-2605599.

In view of its possible relevance for domestic macroeconomic objectives, such as foreign exchange revenues, employment and industrial growth, the mining sector is subject to direct or indirect public control in several less developed countries (LDCs). Except for the limited market liberalisation recently pursued by some national mining investment programmes, this also applies to all former centrally planned economies. The objectives listed above are supposed to influence the supply responsiveness of state controlled mines, so that these mines can be expected to react to changing market conditions in a substantially different way compared to mines under private sector control. This hypothesis can however be properly evaluated only if considered within a broader framework, which accounts for other specific characteristics of mineral supply.

The difficulty in collecting suitable data may explain why most of the studies on the short- and medium-term performance and determinants of supply of a mineral commodity do not rely on econometric estimations, while these analyses are often focused on descriptive statistics and policy recommendations. The few econometric studies aimed at testing for a particular mineral the *ownership and control* and other hypotheses on the market behaviour of mines use either (i) pooled data, aggregated according to features of producer countries and companies, or (ii) national mineral production time series.[1] The latter approach is excessively macro oriented, so as to be unable to provide a solid base for a discussion of issues largely of an institutional and microeconomic nature. Moreover, if a small number of countries is chosen, even deductions and generalisations at a macroeconomic level can be doubtful, especially since they are necessarily based on few time observations. As far as the former approach is concerned, in some cases it avoids these constraints, but it equally runs the risk of forcing *a priori* interpretations across types of mines (e.g., small- versus large-scale operations) or countries (e.g., African versus Asian LDCs, or highly mineral-dependent as opposed to relatively more diversified economies). In this way, different hypotheses on standard supply behaviours are tested on country or company groupings, thus possibly losing relevant information.

Further criticisms could be levelled against these studies because of failing to account for by-product or co-product[2] extraction activities of individual mines or mineral regions: consideration is rather given to commodity substitution effects on the demand side, although these effects are supposed not to be strong enough in the short run as to justify their introduction and modelling in the econometric applications.[3] Finally, the direction of causality, e.g., typically, balance of payments position versus supply, or the price-supply relationship, is not empirically tested, but rather assumed *a priori*. This analysis endeavours to redress some of these drawbacks and constraints, by examining 11-year supply series for a number of major mines in 15 developing and Eastern European economies, with reference to four metals whose ore deposits are characterised by frequent geological association, namely copper, lead, zinc and silver. The analysis is organised as follows. First, factors affecting ore reserves and mineral supply are reviewed, with attention especially paid to these four metals. This is followed by a discussion of data sources, geological characteristics of metal by-product occurrences, econometric approach and estimates. These results are briefly reexamined in the conclusions.

Determinants of ore reserves and mineral supply

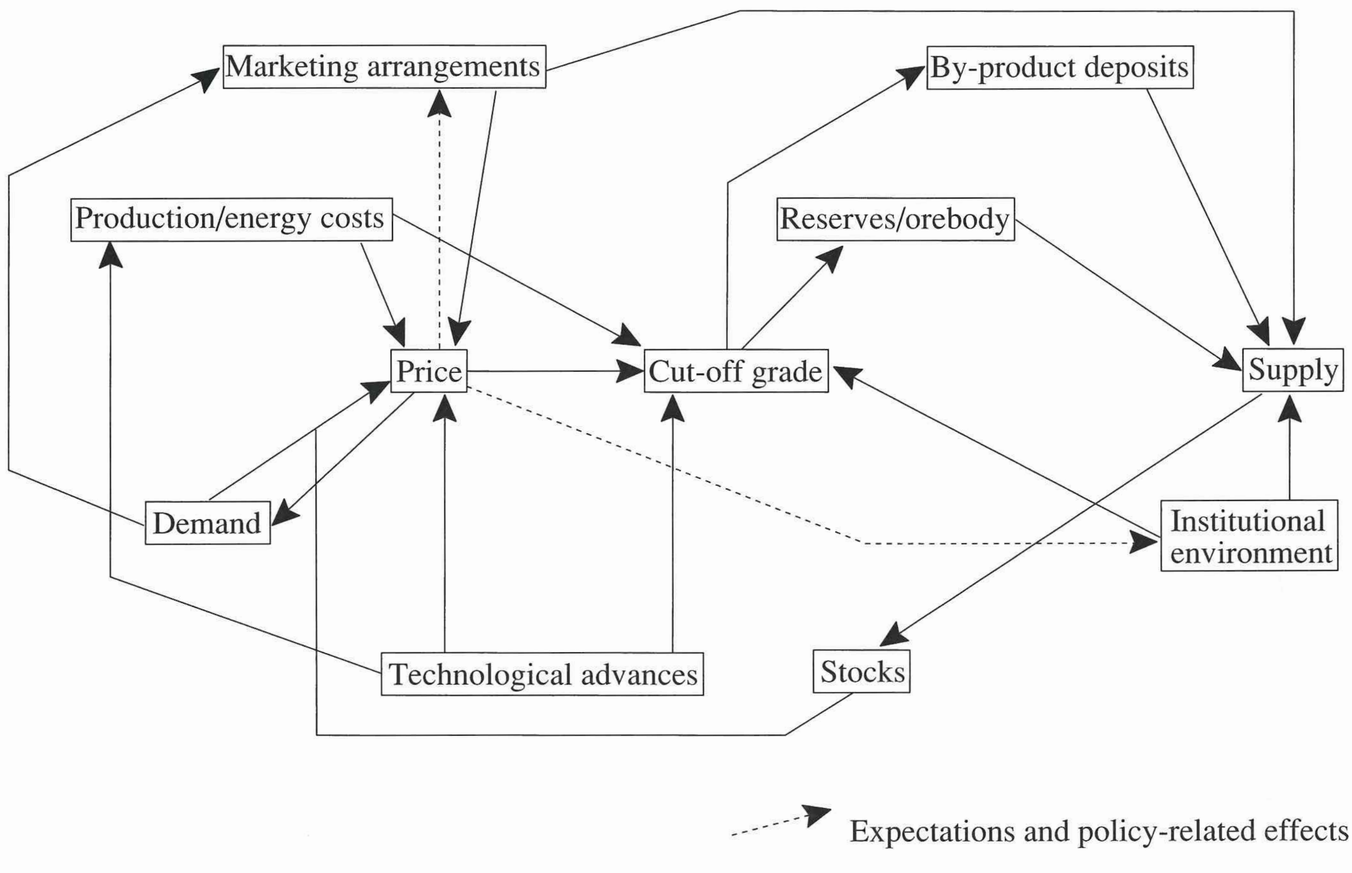
Preliminary to a study of metal production behaviour by individual mines or countries, a distinction should be drawn between *resources* and *reserves*. The former refer to the stock of mineral deposits contained in the earth's crust, up to a certain depth level: a conventional depth level of 4.8 km below the land surface has been proposed.[4] Abstracting from its progressive depletion and ongoing formation of new deposits (such as ocean-floor manganese modules), the resource base is treated as geologically fixed. The latter term, by contrast, is used for that part of mineral resources which can be extracted under present economic and technological conditions, and as such it is subject to continuous revisions. Within each of the two categories further classifications can be made, according to the degree of knowledge/uncertainty and economic feasibility associated with a natural concentration of minerals. Among these distinctions, particular importance as an indicator of potential short-term supply of a mine is the concept of *orebody*, namely an economically mineable deposit which has been identified and measured so as to render it available for immediate exploitation. Orebodies can vary substantially not only over time, but also across different locations in terms of minimum cut-off grade, which allows a reasonable payoff period on extraction operations.[5]

The scope for expansion or contraction of supply of a certain mineral commodity will therefore depend on a group of factors. Many of these factors tend to influence also the extent of reserves and orebodies, and to mutually interact. They include:

- the rate of exploration and discovery of new seams, and the possibility for financing these activities;
- the development of new technologies for extraction, and for waste and scrap mineral recovery;
- the paragenetic association of that mineral with other minerals, that is the simultaneous occurrence of, e.g., copper and cobalt, or lead and silver[6];
- the infrastructural development and physical accessibility of the area where the deposits are located;
- the institutional environment of the producing country, reflected by issues such as taxation policy, investment incentives, political instability and environmental regulations; and
- the performance of costs of extraction and processing, international mineral commodity prices, and the kind of possible marketing agreements with consumers.

The complexity of the relationships linking some of these factors is schematically

Figure 1. Some inter-linkages between mineral supply and related variables



illustrated by Figure 1. Technological progress can positively affect the capacity to mine lower grade deposits, directly, or indirectly through a reduction of the operating costs of a representative average mine. However, the opposite effect does also take place, if these improvements promote substitution effects between different minerals, or foster less mineral-intensive production processes. The relationships of these variables with the price of the mineral commodity can similarly follow different paths. On the one hand, a mineral price increase allows a larger quantity of ore to become mineable, thus reducing the cut-off grade. On the other hand, in the long-term a commodity price decline can be determined by the ability to mine increasing quantities of low-grade ore, which expands the base of reserves and orebodies and may thus increase supply at a rate outpacing the growth in demand, with an accumulation of mineral stockpiling. Furthermore, a reduction in energy costs could depress the price of certain minerals, thus having a contradictory impact on the average and cut-off ore grade if this indirect price effect is taken into account.[7]

A favourable performance in the international mineral price can also positively influence, through its ore grade effect, the capacity to explore large and otherwise untapped lower grade by-product deposits. Silver is for instance found as a by-product in the ores of base and precious metals, namely copper, lead, zinc, gold and platinum. Three fourths of world's silver production is estimated to derive from the processing of copper, lead and zinc ores. In the early 1970s, identified resources of by-product silver were estimated to be fifteen times greater than those with silver as a main product.[8] Polymetallic deposits are typical of the four metals selected for the empirical analysis, although changes in average and cut-off ore grades are believed to have differed, according to the prevailing geological environments of these metals. Since identified reserves and known resources of lead and zinc are geographically more widespread than silver and, to some extent, copper, and their occurrences are more frequently characterised by small by-product deposits, their cut-off grades are more difficult to estimate and are thought to have decreased only slightly over the last few decades (Table 1). By contrast, copper has benefited from large-scale open-pit operations: its by-product minerals include, besides the other three metals considered here, nick-

Table 1. Examples of paragenetic associations: grades of the ore for four metals

Mine area or deposit	Country	Metal content (per cent) Cu	Pb	Zn	Ag
Big Stuby	Australia (West)	0.1–0.3	3	14–21	20–840 g/t
Kidd Creek	Canada	2.46	2–25[a]	6	70 g/t
		[1.25]	[0.4]	[9.75]	[133 g/t]
El Salvador	Chile	0.5–(1.6)	–	–	1.5 g/t
Shuikoushan	China (South East)	–	10–30	10–24	up to 600 g/t
Um Gheig	Egypt	0.13	2.26	15.8	12.7 g/t
Cobán	Guatemala	–	[20]	[36]	[435 g/t]
Rajpura-Dariba	India	0.2	2	7	100 g/t
Rampur-Agucha	India	–	1.6	13.5	52 g/t
Bou Bekker	Morocco	–	2–5	0.1–0.3	0.005–0.12
Tsumeb	Namibia	2.2–(11.4)	(3.3)–15.7	7.1–(24.4)	–
Tverrfjellet	Norway	1	–	1	10 g/t
Tarnowskie Góry	Poland (Silesia)	–	1–2	4–5	–
Panguna	Solomon Islands	0.48	–	–	3 g/t
Garpenberg	Sweden	–	3	5	120 g/t
Sikitiko-Kapapa	Tanzania	1.2	6.9	–	28 g/t
Kasekelesa	DRC (ex Zaire: Shaba)	0.2–0.7	0.05–0.45 (25)	–	–
Kipushi	DRC (ex Zaire)	10–40	3–25[a]	10–15	–
Broken Hill	Zambia (south of the Copperbelt)	–	(12.7)–24.8	(22)–34.9	42.5 g/t

Notes: In parentheses: local occurrences (collateral to the primary ore). In square brackets: average ore grades of annual production. a = usual range of ore grades for type of geological occurrence of the deposit. – = not reported, or present only in trace amounts
Source: Vanecek, 1994, chs. 3–8, 12.

el, cobalt, molybdenum and platinum.[9] Although these by-products constitute a relevant alternative source of revenue for copper mines and producing countries, copper by-product minerals are often present in relatively smaller quantities, while average ore grades and reserves have undergone more rapid changes for this metal. Specific features regarding the four metals focused on here, are further considered below.

The local price and supply of a mineral commodity are affected by the market structure and organisation of producers, the exchange rate, and sales modalities. At a producing country level, a mineral market characterised by scattered, unorganised producers, less integrated forward with semi-manufacturing industries, can be expected to be less responsive to demand changes and affected by higher price oscillations. Examples are provided by copper as opposed to aluminium.[10] If the degree of concentration of corporate control over mining operations among the most relevant controlling companies/states is considered, the four metals examined here are notably more dispersed than several other metals, such as diamonds, platinum, iron ore, nickel, molybdenum and tin (RMG database). The share of total world production controlled by the five largest producing companies/states in 1994 was estimated to range from 21.6 per cent for silver to 34.4 per cent for copper, with zinc and lead being intermediate cases. The twenty largest producing companies/ states account for nearly 50 per cent and 72 per cent of world supply, for silver and copper respectively.[11] Given a certain mineral, at the level of an individual controlling company, a higher supply responsiveness to changing price and demand conditions can be expected in the presence of a particularly high international involvement and diversification of mining operations. The supply of loss-making mines may be reduced more radically by large corporations earning profits from mining activities in alternative sites than by enterprises concentrated in one or few mines in one country only, especially if the latter are state enterprises and unless a default is unavoidable. For silver, for instance, the UK-based Rio Tinto owns and controls mines in seven countries of different continents, even if this enterprise only occupies the 15th ranking as a major producer. With reference to copper, Anglo-American Corp. (AAC) similarly exercises control over mines in several countries in Africa and Latin America.

Table 2. Mine production: price and cross-supply elasticities (1984–94)

Mine(s)	$price_{-1}$	Pb	Zn	Ag	R^2	DW
Copper						
Tsumeb[a] (Namibia)	0.94 (5.09)	-0.42 (-5.84)			0.90	1.93
Black Mt.[a] (South Africa)				1.39 (3.78)	0.86	2.06[e]
Mamut (Malaysia)	-0.28 (-1.91)[c]				0.29	1.60
Turkey	0.43 (1.55)		-0.84 (-1.98)		0.49	1.68
Centraminas (Peru)		-2.97 (-2.68)[d]	3.10 (3.34)[d]	0.95 (5.44)	0.82	2.33[e]
Bulgaria	-0.98 (-4.40)				0.68	1.61
Poland	-0.37 (-2.58)[d]				0.77	1.97[e]

Lead

Mine(s)	$price_{-1}$	Cu	Zn	Ag	R^2	DW
Rosh Pinah[a] (Namibia)	-0.22 (-1.41)[b]			0.34 (4.36)	0.66	2.44
ZCCM (Zambia)			0.78 (9.05)	0.75 (2.24)[d]	0.96	2.93
Nilzco (Iran)	-0.89 (-3.01)				0.50	2.47
Turkey	0.58 (3.26)				0.60	2.90
Comibol (Bolivia)	-1.51 (-1.98)[c]			1.18 (3.36)	0.61	2.89
Bulgaria	0.30 (2.18)[c]				0.95	2.17[e]
Romania	-0.47 (-2.82)[d]		0.48 (2.19)[c]		0.57	1.75

continued...

A devaluation in the exchange rate has uncertain effects on mineral supply. While it can protect local producers' revenues in local currency from international price slowdowns, it can negatively affect the cost side, with higher costs in foreign currency of shipping, repayments on foreign loans and imported capital goods. Similarly to the exchange rate effects, mineral sales agreements, such as futures contracts, producer prices or term contracts, often tend to protect national pro-

...continued

Mine(s)	$price_{-1}$	Cu	Pb	Ag	R^2	DW
Copper						
Gecamines	-0.99	0.36		0.96	0.95	1.56
(Zaire)	(-1.69)[c]	(1.65)[b]		(4.94)		
Bawdwin	0.85			0.91	0.87	2.47
(Myanmar)	(2.40)[d]			(8.04)		
Nilzco	-1.11				0.58	1.94[e]
(Iran)	(-1.81)[c]					
Turkey		-0.41			0.47	1.35
		(-2.85)				
Comibol	1.36				0.45	1.65
(Bolivia)	(1.34)[b]					
Bulgaria			0.89		0.98	2.75
			(21.1)			
Poland	0.18	0.96			0.80	2.31
	(1.92)[c]	(5.92)				

Mine(s)	$price_{-1}$	Cu	Pb	Zn	R^2	DW
Silver						
Black Mt.[a]			1.07		0.96	2.53
(South Africa)			(15.5)			
ZCCM		1.81			0.59	1.42
(Zambia)		(3.58)				
Ertsberg[a]	0.38				0.70	1.71[e]
(Indonesia)	(1.43)[c]					
Mamut		0.93			0.81	2.29
(Malaysia)		(6.25)				
Turkey	-2.00				0.63	1.80
	(-3.72)					
Centraminas	0.31				0.41	1.89
(Peru)	(2.51)					
Mantos B. Min.[a]	-0.32	1.15			0.83	1.70
(Chile)	(-4.79)	(3.52)				

Notes: The R^2 measures have been adjusted for degrees of freedom. DW indicates Durbin Watson statistics, and *t*-statistics are presented in parentheses under the estimated parameters. All coefficients are statistically significant at the 1 per cent level, except where indicated by notes b-d. a. private-controlled mine; b. signicant at the 20 per cent level; c. signicant at the 10 per cent level; d. signicant at the 5 per cent level; e. DW-statistics obtained from the Hideth-Lu procedure.

ducers from the vagaries of international prices, while being in some cases suited to the long-term security objectives of buyers.[12] Long-term purchase contracts, covering from one to fifteen years, are thought to have been responsible for the copper mining overproduction in countries such as Chile, Papua New Guinea and Indonesia. In South Africa, term contracts applied to copper and other base metals are mostly limited to a period not exceeding one year and are often flexible, by allowing a company to sell a proportion of the mine product at spot prices during price increases, while reducing this proportion whenever the opposite occurs.[13]

In terms of the institutional environment, the *social* objectives of state-owned enterprises (SOEs) have been focused on by some authors in order to explain their different supply behaviour, compared to the profit-maximising private mining sector. In this view, the supply response of SOEs to fluctuations in mineral prices would be highly dictated by policy- and expectations-related reasons. Wolf hypothesizes a *trade-deficit ceiling* in state planners' decisions to allocate exports, whereby, as the actual deficit approaches this ceiling, SOEs become increasingly price-insensitive and are forced to increase their export supply to fill the potential foreign exchange gap. Similarly, according to Dobozi, when world mineral prices fall short of the price required to achieve a minimal target revenue, the price elasticity of supply becomes negative. This behaviour is likely to lead to procyclical effects in the medium term, especially if all major producers of the mineral are contemporaneously affected by severe balance of payments problems. Following another explanation of a negative covariance between mineral prices and SOEs' supply, the inefficiency and heavy taxation burden of many SOEs (although this supposed tax treatment is often contradicted by favourable terms) may be responsible for reduced efforts of exploration and capacity maintenance by these companies. This eventually leads to supply contractions along with temporary upward-pressures on prices.[14]

Another part of the literature concerned tends to stress factors other than the ownership and control. Some studies distinguish between efficient and inefficient public companies and mining institutions, with the latter located especially in Africa (except for South Africa and few other cases) and Eastern Europe, and the former in Asia and Latin America. Rather than geographical distinctions, Radetzki emphasises the lack of experience by a number of SOEs, and of political will by local governments, in dealing with foreign investors, so as to result in a *de facto* limited control compared to 'mature' SOEs, even when the latter type of SOEs may hold smaller shares of the equity. In terms of recent developments in mining, if adequately monitored by public authorities the private sector has proved, in some cases, to better comply with public goals such as environmental sustainability (e.g., the case of Guinea discussed in Warhurst and Bridge).[15]

In an analysis by Stobart on the international markets for five base metals, the inelasticity, or even negative price elasticity, of supply for LDCs' mining companies is attributed to (i) the objective of these companies to maintain a minimum cash flow to service debt obligations, and (ii) public support programmes implemented during recessions and demand slumps. This phenomenon is considered to have been particularly acute for some large mining operations heavily reliant on foreign and domestic borrowing. Although the public sector is likely to have privileged access to financing, LDCs' governments may decide to subsidise private mining in order to sustain foreign exchange and employment, while also accounting for debt repayment needs of these companies. Furthermore, in both industrial and developing producer countries, there would be a general tendency in modern mining towards an increasing share of fixed costs, thus forcing the companies to keep mine operations at full production capacity.[10]

According to Markowski and Radetzki, a relatively higher share of fixed costs affects the mining sector in poorer economies, thus rendering copper supply in these economies price-insensitive.[16] Their study does not support the relevance of the state/private ownership criterion: in countries experiencing nationalisations in the mining sector in the late 1960s and 1970s there would be no evidence of structural breaks and changes in mineral supply behaviour before and after the state takeovers. According to these authors, state ownership and low or negative supply elasticity are not linked by a causal relationship, but they are both typical of economies with a high dependence on mineral commodity exports, such as Zaire, Zambia and Chile for copper. These countries often happen to be relatively poor economies. Independently from the prevailing ownership structure, governments of LDCs with a heavy dependence on copper exports as a source of foreign exchange earnings may have tried to force the copper industry to maintain output levels during years of price slump, for general social and economic reasons. The indirect foreign-exchange-saving impact of the development of domestic supply of certain minerals in LDCs is not questioned by Gocht, Zandop and Eggert,[17] with reference to substitution effects with imported minerals, e.g. coal versus petroleum. However, the role of mines as a policy instrument for balance of payments re-equilibrium and a provider of foreign exchange is believed by these authors to be overstated and limited to relatively more developed LDCs. In very poor economies, such as Burkina Faso or Sierra Leone, the potential benefits of increased mineral exports can be expected to be more easily offset by increased import requirements by the local mining industry of capital and intermediate goods.

The supply of minerals is therefore subject to various geological and market-related factors, which prevent a quick adjustment of supply to changes in demand and international prices. A distinction is usually drawn between a low short-run price elasticity of supply (due to output and capacity constraints), and higher-than-unitary long-run elasticities (constrained by known deposits and technology developments). The exploration and opening up of new deposits, stimulated by increased demand, can even require several years of delay. However, for an individual mine or producing country with unutilised production capacity and sufficient reserves, a supply adjustment can be assumed to occur at least partly with a one-year lag.[3] The extent and direction of this adjustment can be attributed to such diverse aspects as ownership and control structure, kind of state intervention, degree of corporate concentration, distribution of mining costs, infrastructural development, and availability of mineable by-product deposits. Studies on this topic provide controversial suggestions and empirical findings, so as to stimulate research on a higher level of disaggregation.

Econometric analysis on mine production data

Statistical information and characteristic geological associations between the four ore metals

The following analysis has relied mainly on statistical information of a computerised database set up by Raw Materials Group (Raw Materials Data), which includes detailed statistics on ownership and production by 34 major minerals and over 8000 companies. Production time series data for each company, as well as respective country totals, cover the period 1984–94. *Mineral supply* for the four minerals examined here is defined in terms of actual production in kilotonnes, for the base metals, or tonnes, for silver. The choice of 1984 as an initial year looks suited to the purposes of this analysis, being considered a break year from the previous tendencies towards state ownership control in several mineral economies. A liberalisation of mining investment regimes and state disinvestment from mining operations have been taking place in numerous LDCs especially since the late 1980s.[18]

Features and changes in the ownership pattern are recorded by RMG for each company: the ownership information by company is used to construct hierarchically structured groups, from (subsidiary) mineral producers and exploration enterprises at the bottom, through holdings and other intermediary companies, up to controlling companies at the top. The RMG corporate control model is based on both the level of ownership and the structure of management, eventually supplemented by additional information such as board membership, and standardises to some extent the information on corporate control as variously defined by producer countries. Whereas specific attention has been addressed here to SOEs, defined as mining enterprises with a minimum of 50 per cent of state control, for the sake of comparison a few major private controlled corporations/mines have been included (Table 3).[19] The availability of complete and reliable series and the relative importance within a producing country's mineral supply were the criteria followed to select these mines. For a few countries where the state has a (nearly) total control of mining operations, and where no complete information is available at a company level over the whole sample period, national production data were used.

Supplementary statistical sources used for the analysis included Roskill, for commodity prices in constant terms, and World Bank, for current account balance to GDP ratios.[20] All four minerals are characterised by highly volatile international prices. If weekly data representing recent trends are compared (1991–95), copper and lead prices seem to follow to some extent a similar V-pattern. While over this period the lowest trough is identifiable for all three base metals in the second half of 1993, the silver price appears to have traced the trends of other precious metals (gold and platinum). The common geological occurrence of by-product associations among these metals is reflected by the similarity in the geographical distributions and national shares of their world supply (RMG database).

According to the geological features of the ore, paragenetic associations concerning the four minerals can be found in different environments. The following different types of rock and deposit are identified at an aggregate level:[21]

a) Sedimentary, metamorphic, and volcanic environments. This category includes (i) Pb-Zn deposits in carbonates and arenites, mostly found in limestones, sandstones and shales, and (ii) Cu-Pb-Zn-Ag deposits in volcanic environments. If predominantly copper-bearing, stratiform deposits, which can be included under point (i), often have a copper grade of 1.2–5 per cent. By contrast, porphyry copper-type deposits are found to have a copper ore grade mainly ranging between 0.2 per cent and 1 per cent.

b) Igneous rocks and vein deposits. This kind of deposits, which is generally richer in copper content (1–10 per cent) than the heterogeneous category under a above, includes (i) Cu-Pb-Zn-Ag sulfide ores in hydrothermal vein fillings, and (ii) Cu-Zn or Pb-Zn-Ag metal vein deposits. The latter deposits are often found in association with arsenic and antimony.

Examples of the first type of paragenetic ore formations are represented by mine deposits in Australia, Canada, Brazil (Bahia), Chile, Iran, Papua New Guinea and other Pacific islands, the Copperbelt in southern Zaire and Zambia, Scandinavia, and Poland (Silesia). The Igneous Bushveld in South Africa, Tsumeb in Namibia, as well as some deposits in the CIS, constitute examples of the second, less common group. Even within national boundaries, the ore grade can vary significantly: in some cases this variety is reflected by reversals in the sequence of occurrence of a metal in ores located in different regions. Table 1 illustrates some examples of paragenetic associations in deposits bearing at least two of the four metals, and located in different world regions (ore grades for other metals eventually occurring in these deposits, such as typically cadmium, molybdenum and gold, are not included).

Table 3. Ownership and control (1994)

Mine	State	Local private	Foreign
Bawdwin	100 per cent		
Black Mt.		AAC-GFSA	Phelps Dodge (USA)
Centraminas	100 per cent		
Comibol (Corp. Minera de Bolivia)	100 per cent		
Ertsberg	9 per cent		Freeport (USA) Rio Tinto (UK)
Gecamines	100 per cent		
Mamut	49 per cent		OMRD (Japan)
Mantos Blancos Min.		–	AAC-De Beers (South Africa)
Nilzco (Nat. Iranian Lead and Zinc Co.)	100 per cent		
Rosh Pinah		Lidchi	Iscor (South Africa)
Tsumeb		–	AAC-GFSA (South Africa)
ZCCM (Zambian Copper Consolidated Mines)	60 per cent		AAC-De Beers (South Africa)

Source: Raw Materials Data, Stockholm.

Estimation results

The econometric analysis has aimed at testing some of the hypotheses investigated above, through an assessment of mine supply responsiveness to mineral prices and major components of by-product production. The main objective has been to check the plausibility of the *ownership and control* hypothesis for individual mines, countries, and metals in terms of the short-term price elasticity of mineral supply, and confronting it with the partly alternative explanation of medium- and long-term mining programmes related to the exploitation of by-product deposits. Unlike previous studies, the problem is examined at a largely microeconomic level, which allows exploring possibly different market behaviours according to varying institutional, regional and geological factors.

Mineral supply for the selected countries/mines has been assumed to be responsive to international prices in US dollars (lagged by one year), rather than to prices converted in domestic currency. This looks realistic in view of the foreign exchange constraint and balance of payments objectives influencing SOEs' production decisions, coupled with the lack of currency convertibility and highly regulated domestic price systems typical of former centrally planned economies and LDCs. Moreover, except for Black Mountain (South Africa), the few private mining operations considered here are dominated by externally located multinational companies, which can be expected to respond more to international prices.[22] Co-product or by-product deposits have been modelled by considering the relatively more relevant supplies as indicative of the presence of main mineral deposits (e.g., typically copper for Gecamines), and hence using them as regressors to possibly explain associated metals with a predominantly lower annual supply (zinc for the above Zairean company). These regressors are modelled in turn as dependent variables in subsequent equations, which relate the principal mineral supply to the respective international price. In view of its high unit value, silver output was treated as a 'driving factor' in a few cases, despite being typically a by-product metal.[23]

Loglinear regressions were applied over the period 1984–94, for each mine/country and metal separately. Statistically significant results are presented in Table 2, except for the constant term parameters. The column for inelastic responses in Table 4 accounts not only for the lack of statistical relevance of the price variable identified by stepwise regressions, but also for the absence of statistically significant results in bivariate supply-price regression equations. On the whole, the results indicate a rather heterogeneous pattern of supply behaviour by mining company and producing country. For example, the Turkish state mineral supply shows a positive price elasticity in copper and lead, a negative price elasticity in silver, and appears to have been price-inelastic in zinc. This heterogeneity is reflected by the low significance of the results obtainable from pooled regressions on the same variables.

An interpretation based on the ownership and control structure is only weakly supported by the econometric estimates. Caution in this respect can also be justified in view of the price elasticity estimates for the private sector, although only few cases have been examined: among the results reported in Table 2, only two mines (Tsumeb and Ertsberg) show standard (positive) supply elasticities, while other four cases are either inelastic or negatively elastic. This may suggest that the hypothesis of a rigid or negatively sloping supply curve holds true to some extent for most mines in developing and transition economies, independently from the ownership and control of the mine. As expected, short-term price elasticities are below unity in absolute values in most cases. Surprisingly, of the three cases with positive price elasticities being close to unity, only one is a private multinational-controlled mine (Tsumeb), while the other two mines with a flexible and dynamic supply behaviour are fully state-controlled (Bawdwin and Comibol for zinc). If supply responses to metal prices are subdivided by metal and world region, however, copper and Africa/Eastern Europe seem to follow to a relatively greater extent a Dobozi-type interpretation: positive supply elasticities are found in only 2 (of which one in private controlled Tsumeb) out of 10 cases for copper, 2 out of 9 cases in Eastern Europe, and 1 (Tsumeb) out of 7 cases in sub-Saharan Africa (Table 4).

According to Dobozi, copper producing countries with a dominant state mining sector are relatively more affected by balance of payments disequilibria and

Table 4. Price elasticity of mine production.
Number of cases by metal and region (1984–94)

Metal/region	Positive	Negative	Inelastic
copper	2	3	5
lead	2	4	1
zinc	3	2	3
silver	2	2	5
Africa	1	2	4
Asia	4	4	3
Latin America	2	2	4
Eastern Europe	2	3	4

foreign debt exposure, with SOEs accounting in some cases for part of this debt. The present analysis considers the price-supply relationship at a disaggregate level, thus allowing a test of responsiveness to balance of payments difficulties across countries/mines. First, twelve countries/mines were ranked according to price elasticity estimates of their main metal production, or to the averages of these estimates if a mine/country's production is rather evenly distributed among different metals. Secondly, a Spearman rank correlation analysis was applied to the elasticity variable versus a variable consisting of the one-lagged period averages (1983–93)[24] of the shares of the current account balance before official transfers in the GDP, for each respective country. The rank correlation coefficient (ca. -0.5) is statistically insignificant (according to the t-test), even after removing three *outliers* (Bolivia, Zaire and Zambia). The negative sign of the coefficient seems even to suggest a contradictory behaviour of mine supply in terms of Dobozi's assumption: relatively more severe current account deficits are accompanied by lower negative elasticities (or positive elasticities in three cases) of supply to metal prices.[25]

Co-product and by-product production in geologically associated metals appears to be a relevant explanatory factor, with only few cases of apparent *replacement* effect between the metals, as revealed by a negative elasticity (Table 2). This seems to occur in copper mining with respect to lead relative to two mines, and copper vis-à-vis zinc in Turkey. Silver as a constituent of base metal ores appears to be highly responsive to copper production in three mines, located in Zambia, Malaysia and Chile, in spite of a relatively low geological occurrence of copper by-products found for Zambia and Chile as a whole compared to other copper producers.[9] Since in their case the analysis uses national supply statistics, results are less accurate for Eastern European countries. In Poland, the production of the four metals is concentrated in a few state mines: the copper-silver mines of Rudna, Lubin and Pólkowice; and Boleslaw, Olkusz and Trzebionka lead-zinc mines. However, the only statistically significant result concerns zinc as a co-product of copper. In terms of standardised beta coefficients, in the cases where both the metal price and co-products are relevant explanatory variables, main and co-product supply is found to be generally more relevant than metal prices for the base metals, while the opposite occurs for silver in the only case which can be analysed to this purpose (Chilean Mantos Blancos).

In view of the changes in the ownership and control of production occurring since the late 1980s in these transition economies, the stability of the estimates over time has been tested, through the application of the Chow forecast test and rolling regressions. Although a fast implementation of privatisation has been limited to small- and medium-sized business and services, while only marginally and slowly affecting the SOEs, the latter enterprises' supply behaviour is likely to have been influenced by the liberalisation programmes adopted for price, consumer, labour and foreign trade markets, and, to a lesser extent, by institutional reforms. Of the three countries examined here, the shock therapy approach followed in Poland was launched in late 1989–early 1990, while macroeconomic reforms in Bulgaria and Romania started in 1990, but they actually achieved greater intensity and scope in 1991 in Bulgaria and a year later in Romania. For these reasons, *ex post* forecast periods were chosen with different initial years: 1991 for Poland, 1992 for Bulgaria, and 1993 for Romania. The only clear case of a parameter change is represented by Bulgarian lead supply: if applied over the period 1984–91, the respective equation provides a statistically significant negative price elasticity of -0.83 (while its co-product association with zinc remains unchanged: see lead and zinc in Table 2). In all other cases, the Chow test and rolling regressions reveal structural stability in the estimated relationships, although a slight movement towards a less negative price elasticity, or away from price-inelastic supply, is observable for Polish copper and zinc.

Conclusions

In spite of a widespread debate on the market distortions induced by the predominance of state corporations in certain production activities, the few empirical analyses carried out for the mining sector do not seem to provide a sufficient base of assessment, in view of problems of data aggregation and econometric modelling of variables. This study has focused on the supply behaviour of state mining in LDCs and Eastern European economies, relative to individual mines and metals. In this concern, the supply of a mineral cannot be considered only in terms of its own or complementary/substitute commodity markets, but it should also be seen in connection with its possible paragenetic associations with other minerals.

Some of the criticisms raised towards statistical analyses on this subject have been examined: these criticisms point to the need for further investigation. For instance, a causality analysis of the relationship between mineral price and supply would require an aggregate general equilibrium model, including variables such as metal stocks and consumption. This goes beyond the disaggregate and partial equilibrium framework established here. On the whole, a disaggregate and case-by-case approach to this issue appears to be justified by the variety of supply responsiveness to market changes revealed by econometric results. This responsiveness is here found to be often inelastic or even negatively elastic to metal prices. This supply rigidity may be explained by such factors as (i) existence of longer reaction lags; (ii) high share of fixed costs; (iii) institutional environment; (iv) location of mine production and lack of sufficient forward linkages within a metal market and for an individual mining company; or (v) geological characteristics (orebodies, polymetallic deposits).

Points (i) and (ii) require longer time series and more detailed statistical information. Although this analysis does not question the importance of the institutional framework in influencing mineral supply, distinctions in average supply behaviour can be made according to different regions and metals, with copper and Africa/Eastern Europe being apparently more consistent with an ownership and control interpretation. From regression results, moreover, whereas the political and legal establishment is likely to be highly influential on part of the private sector as well, this interpretation does not seem to be strictly related to foreign exchange requirements for balance of payments adjustment, or to the level of development of the producing countries. This leads to seek alternative explanations at least for some of the countries/mines concerned, such as the relatively greater involvement of mining SOEs in long-term supply agreements, or, in view of other policy objectives (e.g. employment), the buffering effects of subsidised energy costs, economies of scale, and higher average grade deposits. As revealed by the analysis of former centrally planned economies, the impact on mining of the recent shift towards a market liberalisation in Eastern Europe has so far been slow and minimal. Once longer time series become available, it would be useful to re-run these tests for selected countries, by taking into account the years when major policy reforms were implemented. In terms of geological conditions, the scope for co-product recovery appears to be often more relevant than the international mineral price as a supply determinant for the three base metals analysed, although a clear-cut assessment is hindered by the results obtained for certain mines/countries, where either one of the two factors is found as the only relevant explanatory variable.

Notes

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1. Dobozi (1990); Mainardi (1995: ch. 6); Markowski and Radetzki (1987).
2. Co-production refers to two or more minerals which are recovered in similar quantities from the same mine area or deposit. The term by-product is instead usually associated with the supply of mineral(s) of secondary importance relative to the main mineral obtained from geological assemblages. This distinction may have relevant implications for mineral supply behaviour: by-product output is likely to be relatively more sensitive to the main mineral price, to the extent of eventually being 'protected' from its own mineral price fluctuations. This is reported to occur for instance in the case of molybdenum as a copper by-product (Carvalho and Terezopoulos 1993: 18).
3. Markowski and Radetzki (1987); Dobozi (1990).
4. Govett and Govett (1976: 21).
5. Govett and Govett (1976: chs. 1–2). In the case of copper, in the beginning of the 18th century a common ore grade in metal deposits would be 13 per cent, while two centuries later this percentage would normally range between 2.5 and 5 per cent. In more recent years the ores generally contain less than 0.5 per cent of metal. However, substantial differences can be found among deposits, according to infrastructural facilities and proximity to demand, so as to render some of them economically unfeasible even in the presence of relatively high ore grades. The average concentration of copper in the continental crust is estimated to be still one hundred times lower than presently mineable deposits.
6. Gocht et al. (1988: 168).The term paragenesis can be referred to the sequential formation of associated minerals, rather than to the presence of ore mineral assemblages characterised by a wide variety of ore grades for each metal component (Craig-Vaughan 1981: 142). The conceptual difference appears to some extent purely theoretical: if a metallogenic province is defined as a territory characterised by various kinds of mineral deposits with a common geological history, paragenetic associations constitute different parts of this territory, as "common occurrences of individual kinds of minerals or groups thereof" (Vanecek 1994: 16).
7. Takeuchi et al. (1987: 54); Govett and Govett (1976: 42–43, 56, 141).
8. Vanecek (1994: 447); Govett and Govett (1976: 108).
9. Takeuchi et al. (1987: 62); Chamber of Mines (1990: 26).
10. Stobart (1985).
11. The world production identified by the RMG database for the four minerals in 1994 was 75 per cent for silver, 80 per cent for lead, 85 per cent for zinc, and 91 per cent for copper. The unidentified production is believed to eventually affect the lower ranks only. By comparison, the shares in total world supply of the first five major controlling companies/states were, for instance, 75.4 per cent for diamonds, 40.4 per cent for iron ore, and 42 per cent for tin.
12. A futures contract commits the seller and purchaser to a specific quantity of the mineral at a pre-established future time and at a price determined by a futures exchange in open auction. If the sales price is locked into the current price plus a premium based on expected interest rates, storage or insurance costs, the producer is protected against commodity price volatility (Austin 1984: 340).
13. Takeuchi et al. (1987: 95–97); Austin (1984: 339–340).
14. Wolf (1982); Dobozi (1990); Giraud, quoted in Radetzki (1985: 2).
15. World Bank (1992); UNCTAD (1994); Radetzki (1985); Warhurst and Bridge (1997).
16. The higher proportion of fixed costs would be brought about by (i) the use of similar mining capital equipment worldwide, with most mineral developing economies affected by higher maintenance and transport costs and import duties, and (ii) the comparatively lower level of labour costs and, for major mineral producer countries such as Chile for copper, the near-fixed cost nature of these costs for mines (with high potential restructuring costs and rigid labour legislation in the mining industry) (Markowski and Radetzki 1987: 24–30). In an earlier study, Radetzki (1985: 42, 48–49) argues that a reduction in the share of variable costs and a shift towards higher capital-intensity can be seen as a strategy by SOEs to smooth the negative impact of mineral price volatility, while taking advantage of their relatively cheaper access to capital funding.
17. Gocht et al. (1988: 251).

18. Warhurst and Bridge (1997).

19. Mamut (Malaysia) has also been considered as a SOE (Table 3). Among foreign controlling entities, OMRD is a Japanese consortium of mainly private companies, dominated by Mitsubishi. In 1994 Iscor controlled 51 per cent of Rosh Pinah (Namibia): this mine has also been considered as private controlled, in view of the partial privatisation of Iscor in 1989 and the relevance of local private control (49 per cent). Centrominas (Peru) started some privatisation in 1995.

20. Roskill (1994); World Bank (1995: Table 18).

21. Craig and Vaughan (1981); Vanecek (1994).

22. Dobozi (1990: 9); Adams and Vial (1988: 89).

23. In the case of changes in relative importance of metals produced by a mine over the period (e.g, copper versus lead for Tsumeb), the scope for bi-directionality was investigated. For the Black Mt. lead/zinc/copper/silver mine at Aggeneys in South Africa (south of the Namibian border), a three-stage pattern of co-product metal supply can be identified, whereby copper is a function of silver production, and the latter is modelled by either one of two basic metals extracted in that area, namely lead or zinc. The stepwise regression procedure followed by Rats (the econometric package used for this study) is based on a combined forward and backward selection algorithm accounting for t-statistics and partial correlation coefficients, thus overcoming one of the criticisms raised against this technique, namely the risk of multicollinearity. The literature is however not unequivocal about the usefulness of partial correlation coefficients to this purpose (Studenmund 1992: 193; for a different and more common view: Pindyck and Rubinfeld 1986: 93). A second pitfall, concerning the insufficient theoretical background when a large set of regressors is considered, is also avoided, in view of the assumptions underlying the regression modelling. In strict terms, silver should be modelled as a dependent variable, since it is mostly produced as a by-product of the beneficiation of other metals (Roskill 1997: 91), and its geological occurrence is characterised by a much lower grade than the three basic metals (Table 1). However, a reverse causation is here hypothesised whenever silver appears to have the potential to substantially contribute to mineral revenues. An alternative approach is applied to South African historical data in Mainardi (1998).

24. Due to data unavailability, averages for shorter periods were calculated for Iran and Zaire (World Bank 1995: Table 18). Myanmar, Namibia and South Africa are not included in this analysis; the Ertsberg mine (partly state controlled) and Mantos Blancos have instead been included.

25. Dobozi (1990: 7–9). As in similar studies, this result is subject to the assumption of a high correlation between domestic production and export supply of the minerals, with the latter variable mostly being available only in national account statistics of individual countries.

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