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# The effect of EPA regulations on domestic lead and zinc ore supplies

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The effect of EPA regulations on  
domestic lead and zinc ore supplies

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by

Gary Allen Campbell

A Thesis Submitted to the  
Graduate Faculty in Partial Fulfillment of the  
Requirements for the Degree of  
MASTER OF SCIENCE  
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Signatures have been redacted for privacy

Iowa State University  
Ames, Iowa

1980

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## CHAPTER I. INTRODUCTION

A question of great interest in the study of the economics of natural resources is the apparent failure of the private market to account for the complete costs and benefits of the use of resources. The external costs and benefits associated with pollution, recreation, aesthetics, and other factors are usually ignored or poorly taken into account because of the lack of hard monetary estimates of their impacts. The pricing mechanism, historically, has not taken these factors into consideration, and consequently, there has been a misallocation of resources. The government, acting for society as a whole, has tried to correct this imbalance through legislation and regulation. For example, the National Environmental Policy Act of 1969 states: ". . . to create and maintain conditions under which man and nature can exist in productive harmony . . .", or the National Materials Policy Act of 1970: ". . . enhance environmental quality . . . to anticipate the future materials requirement of the nation and the world . . ." (1, p. 37). This study will look at the impact of this type of government policy on the domestic lead and zinc mining industry.

Mining has always been a very environmentally destructive process. Its methods can cause loss of alternative land uses, erosion, acid drainage, dangerous metal concentration levels, and landscape destruction. The issue is complicated by the fact that the externalities produced by mining are generally inflicted on one group of individuals while the benefits accrue to a different group. Therefore, there has been no tendency for those involved in mining and its supporting industries

to make any effort to internalize the costs of the externalities that they create. This condition has led to the subsidy of mining by the members of society who face these externalities. The government, through recent regulations, has attempted to force mining companies and their customers to pay the true social cost of their activities.

With the introduction of EPA regulations, the domestic lead and zinc industry let its disapproval be well-known. The industry stated that they were producing at the margin of profitability and the new standards would force the closing of mines, cut-backs in production in other mines, and reductions in the capacity of mills and smelters. This situation would result in higher prices and greater dependency in foreign supplies. These foreign supplies could use higher grade ores and did not have to meet strict environmental standards. However, critics suggested that the industry could overcome these problems by developing new and better technologies and procedures.

This difference in opinion can be stated in testable hypotheses form as:

- (1) There has been a decrease in the supply of lead and zinc ores per real price since enactment of the EPA regulations.
- (2) There has been no change.
- (3) There has been an increase in the supply of lead and zinc ores per real price since enactment of the EPA regulations.

This study will attempt to analyze the lead and zinc industry and to determine the effect and magnitude of the EPA regulations on domestic ore supplies. This will be done in four stages. First, background

information on the lead and zinc industry will be presented. This section will be followed by a review of the relevant economic theory. From the framework built of the background and theory, a quantitative model will be developed to test the hypotheses. The fourth section will deal with possible public policies and their applications and implications to the lead and zinc industry. The study will conclude with some summary thoughts.

## CHAPTER II. INDUSTRY BACKGROUND

In developing a quantitative model of hypotheses testing, a basic understanding of the situation and its workings is necessary. To aid the non-technical readers and to illustrate the reasoning for later assumptions, this chapter will briefly outline the technical side of lead and zinc production. This outline will include discussions of topics on the industry, the geology and mining, mineral dressing, recovery, and public policy.

## The Industry

Lead has been used by man for over 6,000 years. Today, it is the fifth most important metal by tonnage in international commodity markets. In recent years, lead has been used domestically in storage batteries, ammunition, cable covering, pipes, paint pigment, and gasoline. Currently, plastic has replaced lead as a cable covering, titanium oxide has replaced white lead as a paint pigment, and copper and steel pipes have replaced lead ones. The use of lead in gasoline due to environmental concerns has also declined. However, the growth and need for lead-acid batteries as well as new uses like dampening machine vibrations and shielding nuclear facilities and waste has caused the industry to grow at a steady, moderate rate of 2 or 3% per year. At this time, there seems to be little competition for lead in storage batteries and probably will not be in the near future. Lead's largest substitute is its own scrap. Lead scrap, of which 75% comes from

batteries, is easily recovered and recycled and as much as 40% is used. Scrap will play an increasingly important role in lead supply as the quality of lead ores decreases.

Zinc has been used since the discovery of brass. It is presently the fourth leading metal by tonnage used in the world. Zinc, as a pure metal, was first commercially produced in the 19th Century and has shown tremendous growth in the 20th Century. However, zinc also has historically appeared greatly influenced by the business cycle and is one of the slowest commodities in recovering from a downswing. This fact is probably linked to zinc's major uses in industry. Due to zinc's physical properties like a low melting point, quick solidifying, and corrosion resistance, it is widely used in die casting, galvanizing iron and steel, and the manufacture of brass. There is some competition from plastic and aluminum in die casting but this is not of major concern yet. Zinc's use in die casting and galvanizing directly links it with the production of consumer durable goods. This situation could explain its relationship with the business cycle. Growth of the industry appears to be in the range of 3 to 4% per year.

The structure of the lead and zinc industry is not highly competitive. Domestic lead production has 80% of the yearly yield coming from seven mines. This percent becomes even more meaningful when one considers that a particular company may (and does) own more than one of these major mines. Overall, twenty-five mines supply 95% of the yearly domestic total. The major domestic companies include

Asarco, St. Joe Minerals, Amax Inc., Bunker Hill, Gulf Resources and Chemical Corp., Hecla Mining, and Kennecott Copper. Domestic zinc is similar--five companies account for 40% of the annual output, and the leading twenty-five mines produce over 90% of the total (24). The major companies involved include the above plus Gulf and Western Industries.

The international structure of lead and zinc is fairly straightforward. The United States and Australia are the two largest producing companies of lead. Canada, Australia, and the United States are the leading producers of zinc. Other major producers are Peru, Mexico, and parts of Africa. The United States imports very little lead (about 5%) but it does import a large amount of zinc (approximately 50% of consumption). The major source is Canada. The United States is not vulnerable to cartel action in zinc because the major suppliers are "friendly" (in relative terms), there exists large domestic reserves which are not quite economically viable at present market prices, and the large number of potential suppliers. Unlike other domestic metal industries, the major lead and zinc companies do not have large foreign holdings (Asarco is an exception). This factor is of particular importance for considerations about import controls since controls would protect the domestic market and not affect any major outside holdings by domestic companies.

Domestic prices are reported on the New York Commodity Exchange as set by the domestic industry. The price is set through market

interactions between the major companies. Historically, the domestic price has been equal to the foreign market price corrected for tariffs, transportation costs, etc. Foreign prices are reported on the London Metal Exchange. The market price is further complicated by the various prices listed in the spot, forward, and future markets.

### Geology of Lead and Zinc

The major minerals for domestic lead and zinc mining are galena ( $PbS$  - lead sulfide) and sphalerite ( $ZnS$  - zinc sulfide, "zinc blende"). Galena is a cubic grey mineral while sphalerite is yellow-brown to black. These two types of minerals are usually found together with pyrite ( $FeS_2$ ). The major exception is the franklinite ores of New Jersey which contain zinc but no lead. Also found in these ores are economical (to varying degrees) amounts of metal by-products like copper, silver, gold, antimony, cadmium, and bismuth. Other basic lead and zinc minerals are: cerussite ( $PbCO_3$  - lead carbonate), anglesite ( $PbSO_4$ ), and zincite ( $ZnO$  - zinc oxide). Most of the world's mined ores are a complex mixture of zinc-lead-silver-copper with zinc being the dominant metal present. An important exception to this norm is the New Lead Belt of Southeastern Missouri which is the largest lead producing region in the world and one of the very few districts with "true" lead ores (mainly galena). In some limited cases, lead and zinc are recovered as by-products of fluospar mining.

The major lead and zinc ore deposits of the United States can be divided into types like - the stratiform deposits of the Mississippi

Valley and Appalachian Mountains and the replacement veins along shear zones of the Coeur d'Alene district. Each region and its type of deposit has unique conditions and problems. Accordingly, this section will describe these differences in situation between the various regions and outline typical mines.

The Mississippi Valley region is a large producer of base metals. This region is particularly known for the lead belts of Southeastern Missouri, the Tri-State (Kansas, Oklahoma, and Missouri) zinc mining district, and the upper Mississippi Valley. Presently, the dominant mining district in the region is the New Lead Belt of Southeastern Missouri with its large reserves of high grade galena. The ore bodies of this region are stratiform beds found between limestone, dolomite, and sandstone layers. For example, the ore in the New Lead Belt is found in the Bonneterre dolomite strata in Missouri. The ore contains galena and lesser amounts of sphalerite and copper sulfides. The formations are at a depth of 400 feet at the northern end of the district and slopes to 1300 feet at the southern end. The thickness of ore varies from 8 feet to 90 feet. Beneath the dolomite is a sandstone layer which contains large amounts of water, presenting a problem for mining. The major mining technique is room-and-pillar (19, p. 206).

Another region of stratiform deposits is found in the Appalachian Mountains. These ores are important sources of zinc with by-product lead and extend from Eastern Tennessee to the Adirondack Mountains

in New York. The orebodies are formed in breccias and are found among greatly deformed and folded limestone and dolomite layers. A typical situation is the American Zinc Company's operation in Eastern Tennessee. One such section involves Knox and Jefferson counties. The zinc ores are found in folded and faulted sedimentary layers - in this case, the Knox dolomite (3,000 feet thick). The major ores are located in the bottom 300-350 feet of this layer. The ores are mainly composed of sphalerite. The thickness of the orebodies are from 8 to 100 feet. The length varies from 200 to several thousand feet and from 25 to several hundred feet in width. This great variation in form and content creates problems for mining. The mining method is open stoping with modified random pillars (19, p. 228).

The lead and zinc deposits in the Western United States are of a different nature. The Coeur d'Alene district in Idaho is an important example. Its deposits are mesothermal in nature and formed as replacement veins along shear zones. The ores are complex and involve zinc-silver-gold-lead with zinc being the dominant economic metal. Silver is a very important by-product here. A typical mine of the Coeur d'Alene district is the Bunker Hill Company mine at Kellogg. The major geological feature of the area is the Osburn Fault (an east-west striking, deep-seated, strike slip fault). The orebodies mined by Bunker Hill form a series of linked veins located in folded, interbedded zones in the quartzites of the Revelt and St. Regis formations. These veins contain galena, siderite ( $\text{FeCO}_3$ ), sphalerite, and quartz to greatly varying

degrees. A large amount of by-product silver is also present. The veins are numerous and of many different forms. Therefore, different mining techniques are used as needed (19, p. 239).

#### Mining Techniques

Mining in its most basic form consists of drilling, blasting, and removing broken rocks. The procedures developed to carry out this sequence, however, are numerous and complex. The general methods common to lead and zinc mining will be briefly sketched in this section.

One very common method, especially in the New Lead Belt, is the room-and-pillar technique. Here, the ore is mined straight on with natural pillars and roof bolts used as ceiling supports. Trackless equipment can be loaded as the ore is removed "full face" (thin beds) or through benching (thick beds). This method is especially suited for gently sloping and fairly uniform bedded deposits. Since mining is done nearly parallel to the surface, it is not feasible to go very deep (beyond 6,000 feet.) Problems with strata control and surface subsidence are also important. The problem of recovering the pillars is also of great concern, economically, since the extraction percent could vary from 60% to 90% depending on your success with the pillars.

Another major technique used in mineral mining is some form of open stoping. Sublevel open stoping which is a very common form used

in zinc-complex ores will be illustrated. Sublevel open stoping is used for steeply dipping orebodies with strong walls. It partitions large blocks of ore between main levels and raises into a series of smaller slices or blocks by driving sublevels. The pattern of sublevels is such that blasted material falls to the bottom of the slope. Pillars of material are left at the top level to support the next major level. This division into sublevels makes open stoping mining safer and easier.

Another form of stoping is shrinkage stoping. Shrinkage stoping is an upward progressing method in which a sizeable amount of the broken ore accumulates in the stope and helps support the walls. Broken ore is drawn off as needed to allow access to unbroken ore. When the stope is completed, the broken ore is removed, leaving the stope empty or to be filled with waste material. This method is best for veins and beds dipping at  $60^{\circ}$  or more with sufficiently strong walls and ores. This method is labor intensive and has difficulty being mechanized.

A common mining method used for steeply dipping veins or beds with weak walls is cut and fill stoping. The ore must be strong enough to stand across the back of the stope. The technique is simply to cut out a stope of ore and use the waste or fill material in its place to keep the walls supported. The feasible use of trackless equipment in this type of mining makes it very attractive for wide vein deposits.

A few surface mines are used in the mining of lead and zinc. The major method for this type of mining is open pit mining. Like its

descriptive name, this method involves a huge pit with benching along its working slope. Removal is done till the final pit slope is achieved in a carefully planned sequence of stages. This method allows a large amount of ore removal in a short period of time. However, this procedure can only be used with a very limited number of orebodies and causes a great deal of surface land damage.

### Mineral Dressing

Once the ore has been mined, it is usually sent to a nearby mill to be prepared for recovery and industrial use. This preparation involves comminution, sizing, concentration, and dewatering.

Comminution involves the reduction of broken ore to the size of the ore minerals. This process is done in two major stages - crushing and grinding. Crushing often begins in the mine to allow easier transportation of the ore to the surface. This coarse crushing is usually done with a jaw or gyratory crusher. Their names adequately describe their actions, and the crushing occurs through massive mechanical force. Cone crushers and rolls are used for intermediate and fine crushing, and they work through the forcing of broken ore through a smaller opening by the motion of the hard steel surfaces of the crushers.

Grinding is necessary to prepare the ore material for froth flotation. Most mills use a circuit of ball and rod mills to accomplish this. These mills are large, hollow metal cylinders that rotate around their central axis. Each mill contains steel balls or long steel rods. A mixture of ore and water is added, and the mills are rotated.

Before the ground material leaves the grinding circuit, it is sized. In lead and zinc mills, this sizing is often done with a hydrocyclone. This sluice is rotated in a cone shaped apparatus. The combination of centrifugal, drag, and gravitational forces separate out the ore particles of desired size and sends them on while the still too large particles are sent back into the grinding circuit.

Another common type of classifier is the mechanical classifier. These classifiers are good for coarse separation and involve constant agitating which induces particle movement and separation. Various types are the spiral, screw, and rake classifier. These instruments are being used less due to their lower efficiency and capacity in comparison with the hydrocyclone. Other miscellaneous methods involve water elutriation (hydroseparator) and various physical means of screening and sieving.

The next stage is the concentration of desired material from the ores. The majority of techniques used in the lead and zinc industry come under two broad headings: froth flotation and gravity concentration.

The biggest boom to the milling industry in recent times has been the development of froth flotation. This technique has allowed much greater selectivity and efficiency in the concentration of economic material from ores as well as the economic use of much lower grade ores. The procedure makes direct use of differing chemical reactivity and surface activity of the various minerals in an ore. It basically renders selected minerals of an ore floatable or sinkable for separation. This process is accomplished through selected types of chemical reagents which

act as collectors, activators, depressants, and frothers. A typical addition per ton of ore is given in Table 1.

Table 1. Reagent use in froth flotation<sup>a</sup>

Reagents Applied	Pounds of reagent per ton of ore
frothers	0.01-0.50
collectors	0.02-2.00
pH regulators	0.02-5.00
depressants	0.02-1.00
activators	0.50-4.00
froth modifiers	0.50-5.00

<sup>a</sup>Source: based on (6).

The most common frothers are pine oil and cresylic acid. They do not affect the minerals, but they produce a stable froth of suitable size and characteristics. Collectors make use of ion attraction to float the desired mineral. These collectors are usually organic compounds like xanthates and fatty amine acetates. Depressants are used when two or more of the ore's minerals have similar floatabilities. A common example is the use of sodium cyanide to separate galena from sphalerite and pyrite. Activators are used to help float particularly difficult minerals (like copper sulphate to activate sphalerite).

Once the chemical reagents are added to the sluice in long series of tanks, agitators (much like those of a washing machine) create a

froth with the aid of air bubbles pumped into the bottom of the tanks. This froth which includes the floated mineral(s) overflows the tanks into a trough. The process continues through a series of roughers (high recovery), scavengers (secondary recovery), and cleaners (high grade). When the process is completed, the concentrates move into the final stages. This process causes the most environmental problems of any involved in milling, especially when  $CN^-$  (cyanide) is involved.

The other general method of concentration which was once quite common and still used in some lead and zinc mills makes use of specific gravity and density. These methods include heavy media separation, jigging, tabling, the Humphrey spiral, pinched sluice, and the Reichert cone. These procedures require a narrow size distribution with good liberation for the component parts. However, since a coarse feed is generally required, problems arise. It is apparent why froth flotation was such an important technological change in the industry. For a better understanding of the issues involved, two common methods used in base mineral separation will be illustrated - tabling and jigging.

Tabling involves the use of a "table" and four factors for concentrating: a flowing film of water, frictional forces, riffles, and a horizontal shaking motion. The feed and water are injected uniformly into one end of a table with crossing tapered riffles. The table is shaken in an asymmetrical manner. The feed then travels to different sections of the table depending on its density and particle size from which it is then removed.

Jigging involves the stratification of particles due to a pulsating fluid flow with the emphasis on particle density. The particles are supported on a perforated base through which water flows in alternating directions (pulsion and suction). This fluid motion separates the particles into lower and higher density zones which can be recovered.

The next stage of milling is dewatering. The object of this stage is to recover the water used in the process and produce a dry product. This process is done through thickening, filters, and driers. Thickening is done in large holding tanks. The concentrates settle out of the liquid to form a mud in the bottom of the tank which is recovered. The process is continuous. Filtering is the production of a moist cake and a clarified filtrate by using a porous membrane which retains the solids and lets the water through. Driers like kilns and fluidized beds are used for the removal of residual water from other dewatering processes.

When the concentrate has completed these stages, it is ready to be shipped to a smelter-refiner for extraction or directly to a buyer for an industrial use. The left-over products (tailings) are disposed of by being placed into a tailings pond (potential environmental problems) or by being deslimed and used as fill for mines and other similar situations. Much of the impact of EPA water regulations falls on the tailings disposal of mills.

### Recovery

The extraction of lead and zinc metals from the mill concentrates can be done in many ways under the general headings of pyrometallurgy, hydrometallurgy, and electrometallurgy. Pyrometallurgy is the use of high temperatures to carry out recovery operations. Hydrometallurgy employs liquid solvents (often aqueous) to separate metals. Electrometallurgy uses electrical energy to extract and refine metals. Some various commercial methods for lead and zinc metals will be considered for each category.

The major extraction-refining methods in the lead and zinc industry employ pyrometallurgical processes. One use of pyrometallurgy in the domestic industry is the roasting of sulfides (like galena and sphalerite) to oxides. Some different techniques are mechanical (hearth) roasting, flash roasting, fluidized bed roasting, and sinter roasting. For example, hearth roasting is done in a vertical, multi-hearth system. The ore starts from the top and slowly works its way down. The ores are roasted as they come into contact with the rising hot gases. The oxidation of the system is sufficient to keep the heat at a high enough temperature to continue the reaction on its own.

Sintering is another pyrometallurgical process. This technique is used to agglomerate fine ores into coarse feed for blast furnaces. A typical procedure involves a traveling belt made up of grates. The charge is ignited and the sulfur is burned off as air is drawn through the charge. The fines fuse together to form a strong sinter cake for blast furnace use.

An important means of recovering zinc is through the reduction of oxide ores and roasted sulfides with carbon. This process is carried out in a close retort. Retorts are clay tubes charged with zinc oxide and fine coal or coke which are then placed in a furnace. Zinc vapor condenses to a liquid which is collected in a condenser placed in the open end of the retort.

The major use of pyrometallurgy in lead extraction is in blast furnace smelting. These rectangular furnaces take charges of lead oxide (from sintering), 10% coke, and a small amount of scrap iron to minimize lead content in the slag. The slag usually contains 30-40%  $\text{SiO}_2$ , 25-45% iron oxides,  $\text{CaO}$ , and as much as 20% zinc. Most lead is smelted in this manner, and it involves the production of large amounts of  $\text{SO}_2$  gas as a by-product of the sintering needed for galena.

A recent development has allowed the smelting for recovery of both lead and zinc at the same time. This method is known as the Imperial Smelting Furnace (ISF). A blast furnace is used to vaporize zinc and liquify lead. If the temperatures are carefully controlled, the zinc is condensed on the molten lead and tapped off. This process presents an economic advantage for certain types of lead-zinc ores.

The use of pyrometallurgy is also important in the refining of lead and zinc. These processes make use of liquid phase separation in the melting systems. For example, silver is recovered from lead bullion by the precipitation of high purity lead at a temperature slightly over

320°C down to 304°C where the enriched silver liquid can be separated. Copper is removed from lead in a similar way called kettle drossing. The liquid lead can be removed from the solid, pure copper with less than 1% copper remaining. This residual copper can be further reduced through the slow cooling of the lead (drossing). Similar processes are involved with the recovery of zinc in the ISF procedure.

Hydrometallurgical operations are not greatly used in the lead and zinc industry yet. Most processes involve the recovery of gold and silver from waste materials. Hydrometallurgy is also used in leaching zinc oxides with sulfuric acid to precipitate out the impurities and leave a zinc sulfate solution for electrolysis. However, with the strong EPA regulations against the production of SO<sub>2</sub>, new hydrometallurgical methods are being developed. As an example, lead-zinc ores can be leached with an aqueous chlorine solution. After being treated with the hot brine, lead chloride is crystallized out and dried. The lead and chlorine are separated and recovered by fused-salt electrolysis. The zinc is recovered from the remaining solution by evaporation. This procedure is particularly environmentally attractive for sulfide ore concentrates (1, p. 110).

The use of electro-winning (one form of electrometallurgy) is very important in the extraction of zinc. Over 50% of the domestically extracted zinc is recovered this way. Electrolysis involves the plating of metal ions on prepared cathodes and anodes from solutions treated with an electrical current. In the zinc industry, the zinc is recovered

from sulfate solutions which are used to control impurities like iron, antimony, arsenic, and cobalt. Electro-winning is also used in the recovery of precious metals from lead. In general, this method is an effective and efficient way to recover metals from low-grade ores (like domestic copper ores).

#### Public Policy

The intervention of government into the production of base metals has been present for many years. The government has justified its actions with the following reasons: to help bring about the independence of the United States from foreign supplies, to bring about conservation of raw materials, to stabilize prices and supplies for the consumer, and to protect the consumer from a miscellaneous list of circumstances. For more detailed study, public policy concerning the lead and zinc industry can be divided into categories - environmental, tax-related, stockpiling, and import controls.

The most recent area of policy intervention and possibly the most important is the concern with environmental issues. Until the mid 1960's, mining and smelting companies had little interest in the protection of the environment outside of catastrophic impacts. However, with the advent of environmental legislation and the dictates of the Environmental Protection Agency (EPA), this condition has greatly changed. Recent legislation affecting the lead and zinc industry include the National Environmental Policy Act of 1969, Clean Air Act of 1967 (with the amendment of 1970), Water Quality Act of 1972, and Resource Recovery

Act of 1970. From these mandates, the EPA has developed the following regulations as of July 1, 1978 (17).

Lead and zinc smelters:

limits of -  $50 \frac{\text{mg}}{\text{dscm}}$  (particles)

0.065 % by volume of SO<sub>2</sub> gas

20% capacity of any visible emissions

Practically, the SO<sub>2</sub> requirement forced the increase of recovery of SO<sub>2</sub> for lead smelters from 32% to 96% and zinc smelters from 51% to 93% (20).

Table 2. Effluent guidelines  $\left( \frac{\text{milligrams}}{\text{liter}} \right)^a$

Mine drainage	Max. 1 day	Average 30 days	Mills discharge	Max. 1 day	Average 30 days
TSS	30	20	TSS	30	20
Cu	0.10	0.05	Cu	0.10	0.05
Zn	0.40	0.20	Zn	0.40	0.20
Pb	0.40	0.20	Pb	0.40	0.20
Hg	0.002	0.001	Hg	0.002	0.001
pH	6.0 - 9.0		Cd	0.10	0.05
			CN	0.02	0.01
			pH	6.0 - 9.0	

<sup>a</sup>Source: based on (17).

No effluent discharge is allowed from gold-silver recovery done at CN mills.

Certainly, the methods needed to meet these standard involve a great amount of expense on the part of the industry. Just how much expense is involved has been the object of much study and projections. Some of the results for the base metal industry are summarized now.

For the Federal Water Pollution Act Amendments of 1972, mining needed a three billion dollar investment in capital to achieve the 1977 goals or 15.2% of total investment (21).

The Clean Air Act of 1967 (to be met by 1976) involved the physical dimensions as illustrated by Table 3.

Table 3. Physical levels of emissions<sup>a</sup>

Industry	Value of shipment (\$000,000)	Total emissions (000 tons)	Pollution intensity per \$1000 shipment/tons
Copper	1120	2823	2.52
Lead	130	219	1.68
Zinc	260	503	1.93

<sup>a</sup>Source: based on (21, p. 37).

The ratios of pollution intensity for the base metal industry are the highest of all types of United States industries (21, p. 37).

The estimated costs of control are shown in Table 4.

Table 4. Costs of control<sup>a</sup>

Industry	Emission control Investment	Costs (\$000,000) annual	Annual cost per \$1000 shipment
Copper	313	100	46.95
Lead	65	16	104.00
Zinc	41	18	55.31

<sup>a</sup>Source: based on (21, p. 39).

Finally, the estimated 1977 price increases due solely to emission control costs were 5.7% for copper, 8.2% for lead, and 7.1% for zinc (21, p. 41). This study will attempt to measure the impact and accuracy of this and other estimations.

Another aspect of the environmental issue is the use of public lands for mineral extraction. The industry had been working under the legal guidelines of the Mining Law of 1872 which allowed most public lands to be explored and developed by mining interests. However, with the growing opposition to this practice, much of the United State public lands have since been closed to mining activities. This growing opposition to all mining activities has led the industry to carefully plan and study all environmental aspects of a new site (environmental impact studies) to face court suits by environmentalists. The following checklist was suggested at the AIME World Symposium on Mining and Metallurgy of Lead and Zinc in 1970 (19, p. 60).

1. topography - relief of landscape
2. quality of the soil
3. quality of water in lakes, streams, and swamps
4. groundwater - water table, acquifers, recharge
5. quality of the air
6. agriculture - types and values of crops
7. woodlands - type and value of forest products
8. water - fish habitats and abundance of species
9. land - wildlife habitats and abundance of species
10. recreational use
11. county, state, and federal regulations concerning pollution

The large volume of necessary studies and court proceedings needed for every new facility raises the cost of lead and zinc production.

A major incentive in the lead and zinc industry is its treatment under the United States tax laws. Taxes and subsidies are powerful tools in controlling the direction of an industry. In the case of the mineral industries, the programs have acted, as a whole, as an incentive for production. The industry faces the normal business taxes and can make use of accelerated depreciation like other companies. However, the extractive industry can also make use of a depletion allowance (cost or percentage). Most firms make use of what is called a percentage depletion. Under this provision, it allows mine operators to deduct a fixed percent of gross mine income from their net income from mining, subject only to a limitation of 50% of net income. For lead and zinc, the rate is set at 22% for domestic production and 14% for foreign.

This allowance has several effects: (1) independent of initial costs (2) encourages investment in minerals (3) encourages foreign production (4) puts up barriers to new production (cannot get allowance until production begins - 3 to 5 years after the start of development) (5) favors high grade ores.

Another tax which could play a major role in mineral extraction is the severance tax. This is a tax based on the amount of mineral extracted at any given time. Presently, a few states have a mild form of this type of tax. However, the use of this kind of tax could greatly affect and control the actual mining done by a company. If the externality costs of mining could be determined, this tax could be used to make up the difference between the total costs and the market price. Also, this tax could be used to encourage or discourage development of various areas. In actuality, the greatest impact of the tax laws in the lead and zinc industry might well be the uncertainty of what the government will do next.

Subsidies have also been used by the United States government. Public Law 87-347 which was enacted in October 1961 and continued through 1969 is an example. This law provided a subsidy to lead and zinc mining concerns who produced less than 3,000 tons of recoverable metal during any 12 month period between January 1956 and August 1961. Mines of this size are the first to close when price and demand fall and are often marginal in efficiency. Obviously, this law would affect ore supplies.

Another form of policy intervention of the United States government is stockpiling. National stockpiling began in 1938, and the first stockpiling act was passed in 1939. In 1946, the first Strategic and Critical Materials Stockpiling Act was passed, forming the system which exists today. Stockpiling can serve two purposes - to protect supplies or to manipulate prices. The original national stockpiles were formed to protect supplies of badly needed materials for security purposes. Not surprisingly, the use of these stockpiles as buffers for price adjustments has slowly appeared on the scene. The use of stockpiles as an economic force has been very variable and politically controlled. For example, the United States government used its stockpiling policy as an economic tool to aid the domestic industry against a world-wide surplus of production in the late 1950's and early 1960's. Foreign production was growing faster than foreign demand, leading to unfavorable prices for domestic companies. The government, in way of protection, bought and bartered for the surplus foreign production on the stipulation that future production would be reduced. This surplus lead and zinc was imported duty free and added to the government stockpiles. In 1976, the lead stockpile was at 601,000 tons with a new goal of 865,000 tons to be achieved. Zinc was at 374,830 tons with 1,313,000 tons to be the final total. However, stock have not yet been increased from the 1976 levels. Obviously, stockpiling is a very uncertain factor on the market.

The final major category of government policy is in import controls. In this category, the government has several tools at its disposal.

One tool is the tariff. This is a fixed or variable charge added on to the price of an imported good. A high fixed rate can be used for conservation purposes while the variable rate can be used for domestic price protection. Quotas limit the physical amount of a good imported and is a good tool for limiting foreign dependence. The use of tariffs and quotas have been very common in the importation of lead and zinc.

The present tariff policy is based on the Tariff Act of 1930. In the Act, lead-bearing and zinc-bearing ores had a tariff of 1.5 cents per pound levied. Scrap carried a tariff of  $2 \frac{1}{8}$  and  $2 \frac{3}{8}$  cents per pound (23). In 1978, the rates were 1.5 cents per pound for lead ores and 1.67 cents for zinc ores. Lead scrap rates were 2.1165 cents per pound. Note should be taken of the higher tariff rates on scrap over ores. Also, the present tariff on the metals themselves is 1.0625 cents per pound (25).

The justification for the tariffs has been the need to protect the domestic industry from foreign competitors. It seems that foreign producers have higher grade ores, lower labor costs, and lower environmental protection costs. Since the domestic industry does not have much in the way of foreign holdings, they are at a strict disadvantage. Left to the free market, this situation would lead to unemployment and heavy dependence on foreign supplies. Therefore, tariffs are needed. Yet, the United States does subscribe to the General Agreement on Tariffs and Trade (GATT) which urges restraint in the use of incentives which tend to promote exports and raise barriers against other member exporters.

Quotas were used by the government from 1958 through 1965 for the years involved in this study. During these years, lead quotas were met by foreign countries with very few exceptions. However, zinc exporters rarely reached their assigned quota limits. A study done by the government after the first 15 months of the quota usage concluded that: (1) it did not curtail imports (2) it was discriminatory (3) it interfered with normal trade relations (18). Yet the quotas remained operational for another 69 months. It is interesting to consider one of the more blatant discriminations of the quota. Importation of lead and zinc under bond for custom smelting of foreign concentrates was duty free and led to the development of several specialized smelters who depended on this trade heavily. Other smelters did not. The quotas forced the closing of the custom smelters but had little if any affect on other types of smelters. It was a very selective tool.

## CHAPTER III. RELEVANT ECONOMIC THEORY

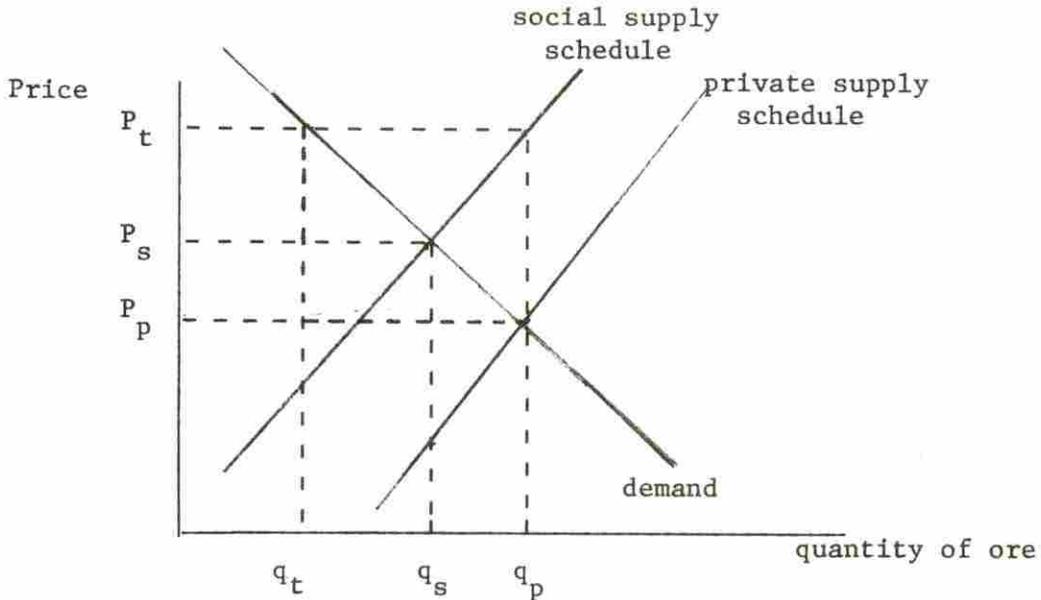
In addition to an understanding of the lead and zinc industry and its operation, a theoretical framework is needed for modeling purposes. This development will be presented in three stages: the market and externalities, the pricing mechanism, and the non-renewable resource depletion model.

## The Market

An economic system has four major goals: efficiency, equity, stability, and growth. In the United States, the attempt to achieve these goals is through a system of markets and government controls. For purposes of this study, efficiency is the major goal to be analyzed. As mentioned earlier, the market failures associated with externalities have been very prominent in the base metal industries. If the mineral extraction and metal recovery process were solely a private good with all costs and benefits captured in the market place, there would be no problem. However, involved in the mining and recovery of metals are the use of air, water, landscapes, and other amenities. These resources are very difficult to define in terms of private ownership and accordingly, to be traded through markets. Unlike private property, no charges can be easily assessed to these common property resources. Therefore, the market value of lead and zinc have understated the social costs of these extracted metals by including only the private costs associated with them. This situation has led to the over-exploration of both the private

property minerals and the common property environmental resources.

Graph 1 shows a simple version of the situation.



Graph 1. Comparison of marginal social and private costs

With the assumptions of constant "marginal damage costs" and fixed technology, the summation of all the firms' marginal private costs is given by the industry private supply schedule. This schedule assumes indifference on the part of the industry about the external costs of their production. The social supply schedule incorporates the external costs of production into the supply schedule. The optimal production point for the industry based strictly on private costs is  $q_p$  at price  $P_p$ . However, the total cost to society is  $P_t$  at which only  $q_t$  is desired. The optimal point of production for society as indicated by the social supply schedule is  $q_s$  at  $P_s$ . Since external costs are very hard to capture,

the market system relies on private costs to decide output levels. As shown by Graph 1, this condition leads to a market failure by causing higher production at lower prices than those desired by society, and at the same time, underproduction of other goods and services.

### Supply and Demand

Within the market structure, it is necessary to understand the operation of the forces of supply and demand, and how they jointly determine price. Usually, lead and zinc are used as intermediate inputs in industry and have derived demands. This demand can be thought of as being influenced by the current and expected prices of metals. Demand will be considered independent of supply and will not play a role in the modeling of the lead and zinc ore supplies.

In theory, supply and demand are brought into equilibrium by adjustments through the pricing mechanism. These adjustments must account for the current (short run) situation and the expected future prospects (long run). In the short run, industrial demand is fairly stable because some of the factors of production are fixed and this limits the substitution possibilities. The amount of desired inventories is the major variable factor. In the long run, all factors of production are variable. Therefore, derived demand is mainly influenced by expected industrial production. Prices adjust as necessary to correct for shortages and surpluses as brought about by changes in short run inventories and long run expectations.

In concluding this section, it would be beneficial to consider the difference between producer and free market prices. The producer price is the price followed by the extraction industry. In the United States market, this pricing is usually derived through an adjusting mechanism. Major metal producing companies announce their metal prices and then wait to see what the other companies will do. The price will finally settle at a common point as determined by market conditions. Also, stockpiles of resources are held by middlemen dealers. These dealers sell and buy at a flexible price that is immediately responsive to supply and demand. Obviously, stocks play a key role in the short run free market price while the producer price is more reflective of stable, major effects over the longer run. All prices used in this study will be yearly average producer prices.

#### Non-renewable Resource Depletion Model

From these basic relationships, a dynamic resource depletion model can be developed. The assumption that the lead and zinc industry exhibits profit maximizing behavior will be made. Mathematically, this can be expressed as:

$$\text{Max } \pi = P \cdot Q - TC(Q)$$

$\pi \equiv$  profits

$P \equiv$  price

$Q \equiv$  quantity of ore

$TC(Q) \equiv$  total costs as a function of quantity

By taking the first derivative with respect to quantity (Q), one gets:

$$\frac{d\pi}{dQ} = \left[ P + Q \left( \frac{dP}{dQ} \right) - \frac{dTC}{dQ} \right]$$

With the assumption of competitive market structures:

$$Q \left( \frac{dP}{dQ} \right) = 0$$

Therefore, the maximum profits is:

$$P - \frac{dTC}{dQ} \stackrel{\text{set}}{=} 0$$

$$\frac{dTC}{dQ} = P \text{ or } MC = P$$

To extend this idea over time, one production period cannot be desired over another for there to be an optimal solution. Accordingly, we must have:

$$\frac{P_i - C}{(1+r)^i} = \frac{P_j - C}{(1+r)^j}$$

$C \equiv$  constant cost

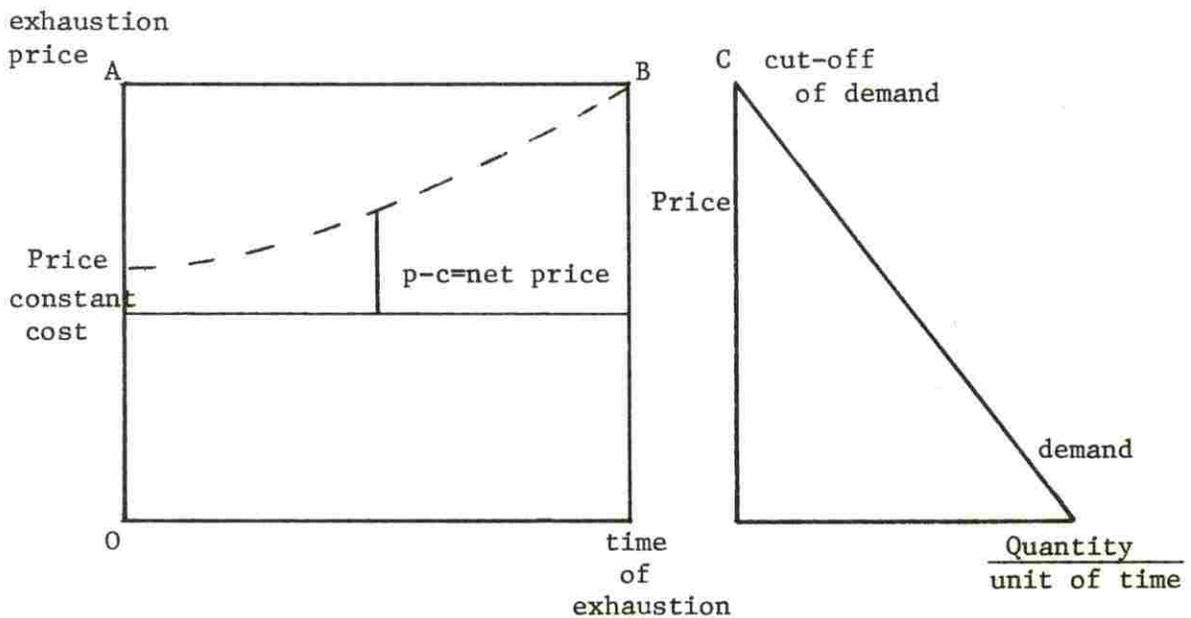
$r \equiv$  discount rate

$i, j \equiv$  time periods  $i$  and  $j$

This expression illustrates that the present value of the net price must be equal for all time periods. The discount rate ( $r$ ) is the private discount rate and not the social discount rate. This distinction is very important when the optimal decision on production is being made.

There are reasons for the private and social discount rates to diverge and to lead to the different optimal production levels.

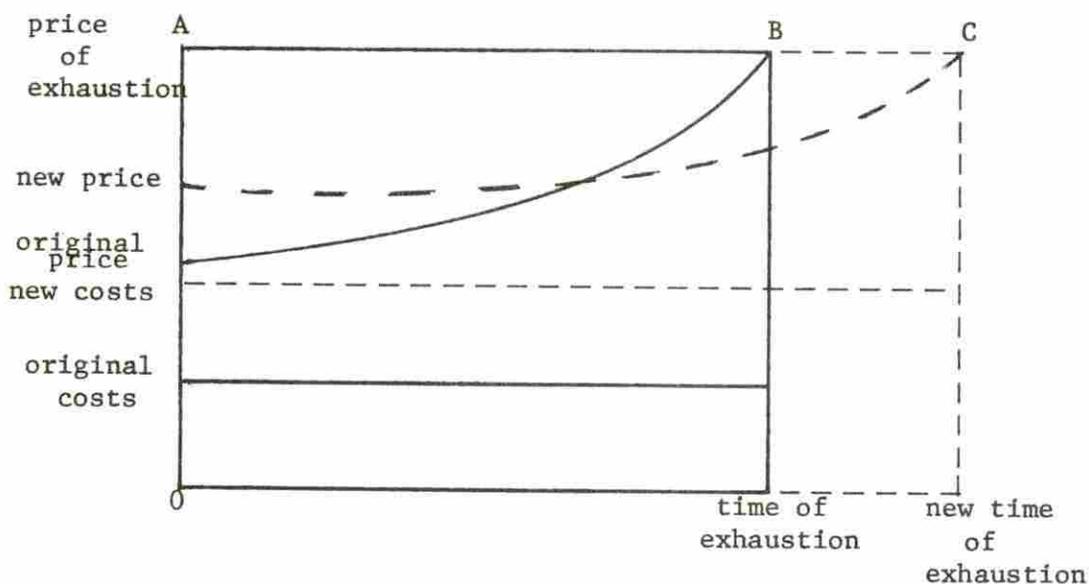
A basic resource depletion model has been developed by Kneese and Herfindahl (11). This model initially makes the following assumption: (1) mining firms sell in a competitive market (2) exploration is technologically independent of its holdings and is subject to exhaustion (3) long run cost curves reflect outlays actually made - expenditures for mining and recovery (does not include rent) (4) rate of discount is positive. For the constant cost case up to a rigid limit, the model is shown in Graph 2.



Graph 2. Kneese and Herfindahl model

This presentation assumes that  $\frac{P_j - C}{(1+r)^j} = \frac{P_i - C}{(1+r)^i}$  and that exhaustion occurs at price A which also brings economic exhaustion. The model can be manipulated to show the impact of changes in market conditions including costs, demand, and discount rate.

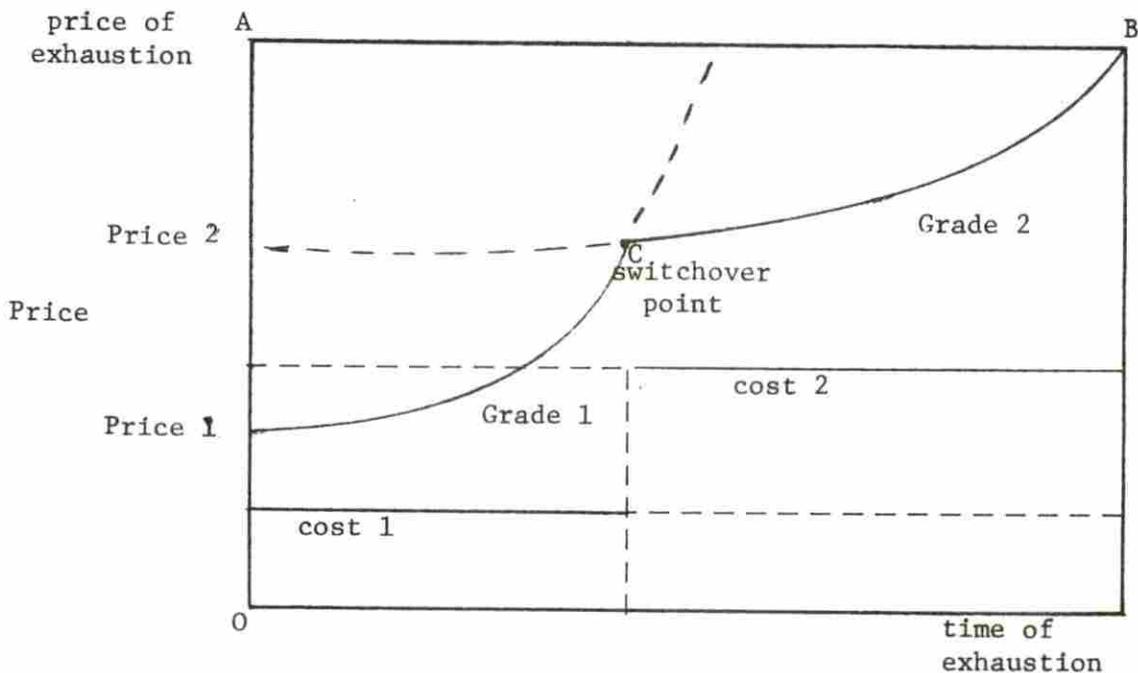
Of special interest for this study is the case of an increase in cost for the industry. If the industry's private costs are below those faced by society, then the purpose of EPA regulations is to raise industry's cost to reflect the true social cost. Graph 3 presents a visual representation of the situation.



Graph 3. Increase in cost

With the increase in costs, the early prices will be higher and the quantity of ore extracted will be lower with correspondingly higher quantities of ores available at that time. Overall, the lifetime of the resource will be increased from B to C in Graph 3 with the same final exhaustion price. In direct application to the lead and zinc industry, this model with its simplifying assumptions suggests that the initial impact of EPA regulations with everything else constant would be an increase in price and a decrease in ore supplies. It would also lead to a longer availability of ore for society's use.

An important usage of this model is the treatment of different economic grades of ore. Graph 4 illustrates this modification.



Graph 4. Different economic grade ores

The more economical grade ore (Grade 1) is used until the second grade becomes more desirable (point C). This situation leads to total economic exhaustion at price A on Graph 4 and may be expanded to the n-grade case. The major conclusion is simple - among known resources better grade ores will be exploited first and the poorer ones later.

This modification of the analysis is very important for purposes of the lead model to be developed in this study. The effect of the New Lead Belt can be studied with this addition. The New Lead Belt is cheaper to mine and mill than other existing sites. This condition corresponds to Grade 1 on Graph 4 coming into production and gradually displacing Grade 2. Accordingly, one should see a shift of ore supplies from Grade 2 producers to the new Grade 1 producers until the economic advantage of the New Lead Belt is removed. Time series data supports this theoretical conclusion (See Appendix B). However, the shift should not be as complete as suggested by Graph 4. The New Lead Belt and older sites like the Coeur d'Alene district are not homogenous in nature. The Coeur d'Alene mines have the possibility of mining ores with less lead and more of the other metals and of having the return from the other metals more than make up for the disadvantage in lead production. This analysis will hold true for other similar situations as long as one remembers to take into account the unique natures of mining sites.

Changes in technology can also be handled with this model. Since technology is considered fixed for an existing facility in this study,

new technologies will be used to bring marginal grades of ore into production competitively with the better grades and can be handled much like the earlier n-grade ore case. This assumption will be used for the short run case associated with the quantitative model. Theoretically, the model can handle the less restrictive situation of changing technologies for existing mines through adjustments in the constant cost curves.

The Kneese and Herfindahl model provides a theoretical standard against which the quantitative model can be compared. The theoretical model, even with its many assumptions, gives an indication of how the lead and zinc industry may react to the EPA standards. The quantitative model will supply insight into how the industry actually behaved. The comparison of the two models will provide evidence on the effect of EPA regulations on the lead and zinc industry and the impact of alternative public policies.

## CHAPTER IV. THE MODELS

Given the basic technical and theoretical framework developed earlier it is possible to formulate a quantitative model to test the hypotheses on the effects of EPA regulations on domestic ore supplies. To achieve this purpose, a multiple regression model based on time series data is used to estimate domestic supplies. A log specification is used because it provides a better representation of the physical situation i.e., physical nature of ore supplies based on the percent of metal content. It also has the advantage of providing own and cross price elasticities of supply associated with the various independent variables.

The years 1953 to 1975 are included in the data base. The year 1968 was used as the start of EPA regulations because enforced regulations involving the industry began to be implemented after 1967. The year 1975 was chosen as the terminal year because of the unavailability of reliable data for later years. Thus, eight years of EPA regulations are included in the analysis. The period 1953 to 1967 represents fifteen years prior to EPA regulations.

The independent variables can be determined, in general, from the theoretical model discussed in the previous chapter. Theory states that supply is a function of own price, prices of related products, factor costs, technology, and exogenous influences. Own price and prices of relevant by-product metals are included. These prices are

indexed to a base year (1967) using a non-ferrous metals price index from "Business Statistics." The indexed prices will eliminate factor cost and price variations due to inflation over time. By-product metal prices of minor importance during the relevant years are not used. Technology is assumed constant for existing facilities. Costs of production, like in the Kneese-Herfindahl model, are considered constant. This assumption will be discussed later. Important exogenous factors that influenced the various metal sectors like quotas, labor strikes, and capacity are included as needed. Finally, the impact of EPA regulations is incorporated into the models to measure the affect on ore supplies. The general functional form of the quantitative model can be expressed as:

$$\text{domestic ore supplies} = f(\text{own price, by-product prices, capacity, exogenous dummies})$$

Data are taken from various U.S. Bureau of Mines-Mineral Yearbooks, "Business Statistics", and CRA-"Econometric Model of the World Lead Industry" (see Appendix B). All physical units are expressed in 1000 short tons. Prices are cents per pound of metal. The producer metal price is used instead of smelter payment for ores because of the complexity and uniqueness of each mine, ore, and smelter.

#### The Zinc Model

Domestic zinc mining is based on the recovery of complex ores containing zinc, lead, copper, silver, gold, and other metals. The

ores vary greatly in metal content from mine to mine. Lead is the major economical by-product common to most zinc ores and will be accounted for in the model. An important aspect of the relationship between zinc and lead is in the recovery of lead concentrates. Lead concentrate producers are penalized at the smelter for any zinc in the concentrate over a prespecified amount. This condition implies that as lead is mined and recovered, a certain amount of zinc production is linked directly to lead production. This situation is particularly true of the New Lead Belt where lead is by far the dominant value in the ore.

Another influence on zinc ore supplies is from the smelter companies. Studies by the government (25) and Charles Rivers Associates (5) show that over 50% of the concentrates for smelters come from their own mines and mills. The output of these captured mines is manipulated by the smelter owners as needed. Lacking means and data to incorporate the smelter owners decisions on production into the model, a proxy variable will be used. The actual production of domestic smelters per year will be used. While the proxy variable is not equal to planned output due to strikes and other unforeseen event, it should be indicative of direction and magnitude.

Government intervention can be viewed as a major exogenous factor. There were several incidents during the period of analysis - tariffs, quotas, subsidies, and stockpiling. These factors involved protection of the domestic industry from foreign competition.

Therefore, foreign effects on domestic supplies are interrelated with government policies. The factor causing the major variations in the domestic ore supplies during the model time period was the quota, described earlier. Another exogenous factor labor strikes, was not an important influence during the period.

Incorporating the modifications required for zinc mining, the following quantitative model was estimated and the results obtained.

$$\begin{aligned} \text{QZK} = & -3.717 + 0.779\text{PZK} - 0.389\text{PLK} + 0.933\text{SMK} + 0.447\text{QLK} + 0.065\text{DQ} \\ & (-3.148) \quad (5.715) \quad (-2.849) \quad (9.777) \quad (3.916) \quad (1.611) \\ & -0.56\text{DE} \\ & (-2.067) \end{aligned}$$

$$R^2 = 0.86 \quad F\left(\frac{6}{23}\right) = 16.6 \quad \text{DW} = 2.37$$

QZK  $\equiv$  log of the quantity of domestic zinc ores

PZK  $\equiv$  log of the domestic, indexed price of zinc metal

PLK  $\equiv$  log of the domestic, indexed price of lead metal

SMK  $\equiv$  log of the actual zinc smelter production

QLK  $\equiv$  log of the total domestic output of lead ores

DQ  $\equiv$  dummy for quota (1 for 1958 through 1965)

DE  $\equiv$  dummy for EPA regulations (1 for 1968 through 1975)

Numbers in parentheses are  $t$  values.  $F\left(\frac{N}{M}\right)$  is for the F-test, and DW stands for the Durbin-Watson test.

All the variables are significantly different from zero at the 5% level except the dummy DQ, which is significant only at the 15% level. The F-test statistic supports an overall good fit for the model. Based

on the DW test, we reject the existence of positive serial correlation and cannot accept or reject the existence of a negative serial correlation at the 1% level of significance. The signs of the coefficients agree with those predicted by economic theory. Price, smelter output, and the use of a quota all have a positive relationship to the supply of domestic zinc ores. The fact that the price of lead is negative suggests that competition exists between zinc and lead in the mining of complex ores. This situation is feasible in mines made up of vein shoots containing ores of different metal contents. This relationship will be retested in the lead models.

The elasticities for the various variables are informative. The own price elasticity of supply for zinc ore is high (0.78). The cross price elasticity of lead (-0.39) is appreciable but less responsive. The importance of smelter producer manipulation (0.93) has important implications in the area of environmental regulations. It is the smelters who produce the large amounts of SO<sub>2</sub> gas which are a particular target of standards. A reduction in smelter production due to more stringent standards will almost have a unitary effect on domestic zinc ore supplies. Smelter production is important because over 50% of domestic ore production comes from captured mines owned by smelter owners. The use of the quota provides a 6% increase in domestic output.

Of special interest for this study is the dummy variable DE. The EPA regulations dummy is significant at the 5% level and has the

expected negative sign. During the years of its effect, the standards reduced the domestic output by 14% annually. If this decrease is totally due to environment standards, it is of major proportions. A reduction in active smelter capacity due to SO<sub>2</sub> gas control standards could be an important factor in this ore output decrease, and has been separated from the overall DE effect.

#### The Lead Models

Due to the nature of the United States domestic lead mining industry, it can be divided into two major categories: Missouri lead which is high grade galena with small amounts of sphalerite and chalcopryrite and non-Missouri lead which is usually part of a complex ore with zinc being the dominant metal. Each region has its own unique conditions and factors, and therefore, will be modeled separately. The statistical and practical need for this differentiation should be apparent from the discussion that follows.

#### Non-Missouri lead model

Non-Missouri lead comes from complex ores with zinc usually being the most dominant metal, physically and economically. Therefore, both the prices of lead and zinc are important. Important exogenous factors are labor problems and government intervention. Labor strikes in the non-Missouri lead region have relatively minor effects because of the diversity of mine ownership. However, Missouri lead production is the dominant factor in the lead market, and it is controlled by a few companies. A strike in the Missouri lead region would have a large

impact on total Missouri lead supplies. Accordingly, the non-Missouri lead region could expand production to take advantage of the shortage. This effect is incorporated into the model by using a dummy variable reflecting the number of months per year that strikes were present. For the period of this study, the variable included five months in 1962 and three months in 1963 for a strike against St. Joe Minerals and four months in 1970 and three months in 1971 for a strike against Asarco in Missouri. Government interventions in lead were of the same form and at the same time as for zinc. Thus, the same dummy for the quota effect is used.

The results of the empirical estimation are:

$$QOK = 4.945 + 0.593PLK - 0.495PZK + 0.040DLM - 0.164DQ - 0.257DE$$

$$(5.876) \quad (2.492) \quad (-3.402) \quad (2.774) \quad (-3.199) \quad (-3.525)$$

$$R^2 = 0.90 \quad F\left(\frac{5}{23}\right) = 29.01 \quad DW = 2.03$$

QOK  $\equiv$  log of the quantity of domestic non-Missouri lead ores

DLM  $\equiv$  dummy for Missouri labor strikes

All the variables are significant at the 5% confidence level. The F-test statistic supports a good overall model fit. Based on the DW test, one can reject the presence of serial correlation, positive or negative, at the 1% significance level.

The signs on the estimated coefficients are of interest. The price of lead and Missouri labor strikes are positively related to the

quantity of ore as would be expected. The price of zinc is negatively related to quantity as is the price of lead to the quantity of zinc ore in the zinc model. The quota dummy, DQ, is negative which is the opposite of the case in the zinc model. This result is contrary to the government's purpose for a quota to help the domestic industry to increase production. However, if the domestic lead industry makes use of market power, the negative sign is not surprising. With the removal of foreign competition, the domestic industry could be cutting back production to cause a rise in lead prices, leading to higher profits. That type of situation is certainly not the government's expressed purpose for the quota.

The model shows that non-Missouri lead ore supplies are slightly more responsive to own price (elasticity = 0.58) than to the cross price of zinc (elasticity = -0.48). This result shows the competitive co-product nature of non-Missouri lead and zinc mining. The estimated price elasticity for lead (0.58) is in agreement with the "initial impact" price elasticity for non-Missouri lead estimated by Charles River Associates using other models (5, p. 71). Missouri labor strikes have a 4% per month positive effect on non-Missouri lead ore supplies. The quota causes a 15% decrease in ore supplies which is approximately twice the effect present in the zinc model. A possible reason for this difference can be seen in the quota history. The zinc quota was rarely reached. The lead quota was almost always filled (25).

Apparently, the quotas were set so that the normal levels of zinc imports (50%) were not affected while the competitive lead imports were limited.

The environment dummy, DE, is significant at the 1% level and is negative. The initial impact of EPA regulations on ore supplies is a 23% decrease in domestic tonnage. This effect is significant. One possible reason for the magnitude of response may involve the age (relatively old) of non-Missouri lead mines. With older facility, the retrofitting with needed emissions control equipment to meet the EPA standards results in higher marginal abatement costs than newer facilities. Another possibility is that the growth of the New Lead Belt during the same time period is somewhat reflected in the dummy variable. Finally, most lead is recovered by pyrometallurgical processes which cause large amounts of SO<sub>2</sub> gas to be produced.

#### The Missouri lead model

The most important factor in the domestic lead industry is the production of Missouri lead. During the relevant time frame, the model can and must be divided into two time periods: 1953 through 1966 when the major source of lead was the "old" Lead Belt and 1967 through 1975 when the New Lead Belt took over production from the older district. This situation creates an unique opportunity to study the "death" of a mining district and the "birth" of a new one. The issue becomes even more interesting when one notes that the New Lead

Belt started production about the same time that EPA regulations began. It should be made very clear that one district does not just close and the other immediately opens - there is much overlapping in planning and actual production.

#### Missouri lead (1953 through 1966)

Obviously, this model will not be involved in the study of the impact of EPA regulations on the industry. However, it could be useful in comparison with the next model and in giving insights into the behavior of old mines.

Since Missouri lead is mainly galena, only the market price of lead will be used. The labor strikes mentioned in the first lead model will be important. Finally, a time trend factor will be used to catch both the closing of the older district and the opening of the New Lead Belt.

The quantitative results are:

$$QMK = 2.034 + 0.965PLK - 0.087DLM + 0.012TM$$

(5.399)    (7.302)    (8.780)    (3.809)

$$R^2 = 0.98 \quad F\left(\frac{3}{14}\right) = 138.08 \quad DW = 2.26$$

QMK  $\equiv$  log of the quantity of domestic Missouri lead ores

TM  $\equiv$  time trend (1953=1)

All the variables are significant at the 1% level. The F-test supports a good model fit. Based on the DW test, we reject the presence of serial correlation at the 1% level of significance. The signs on the estimated coefficients agree with theory.

The own price elasticity of ore supplies (0.97) is high. This suggests that old mines were heavily dependent on the market price to remain in operation, much more than the industry as a whole. As a mine gets older the costs increase because the best ores have already been utilized and only lower grade ores remain. The ores are farther from the transportation centers of the mine and are more expensive to transport. More expense is incurred as mine walls and ceilings require more support for ore removal. Therefore, price changes will have a great impact in the amount of ore which can be economically recovered from older mines.

The dummy variable for labor strikes shows an 8% per month negative effect on ore supplies. This quantitative result gives a 96% decrease in Missouri lead output for a year long strike. This result is close to the intuitive assumption of no production during a strike. The time trend shows a 2% annual growth in ore production during the period analyzed. This factor is probably positive because the influence of the New Lead Belt opening up was greater than the closing down of the older mining district.

#### Missouri lead (1967 through 1975)

This segment of the lead industry should have the effect of EPA regulations built into the initial capital equipment. This extra cost poses no problem since the New Lead Belt is made up of mostly galena and is cheaper to mine and mill than any other domestic and

most foreign ores. The general quantitative model will not work for this segment because it is in the process of starting up production. Production must increase quickly to pay off the very high capital investments. Later, this sector will become more stable and explainable through the basic model. Charles River Associates suggests that only physical limitations on smelting capacity affects the initial production (5, p. 74). Such a model will be used for the empirical analysis.

$$QMK = -1.761 + 1.291CMK$$

$$(-3.169) \quad (13.855)$$

$$R^2 = 0.96 \quad F\left(\frac{1}{9}\right) = 191.96 \quad DW = 1.52$$

CMK  $\equiv$  log of the Missouri active pig lead capacity

All the variables are significant at the 5% level. The F-test supports a good model fit. The DW test indicates no serial correlation at the 1% level of confidence.

Environmental regulations will have their greatest effect in this segment through the impact on smelters. The high elasticity of ore supplies to smelter capacity (1.3) clearly illustrates this point. Any reduction or slow down in growth of smelter capacity will significantly reduce Missouri lead ore output. A complete study then would need a smelter model to analyze this effect.

#### Concluding Remarks

In interpreting the model results, one must use caution. If any explanatory variables are omitted, it could bias the estimated

variables. The environmental dummy variable, DE, could be misleading. The variable could be picking up factors not involved with the environmental issue. For example, production costs are assumed constant in the model. However, during the early years of the model, per unit cost of extraction was probably constant due to changing technology (13). In the later years with increasing energy and labor costs, per unit costs of extraction may have started to increase. If that condition has occurred, the environmental dummy has captured that effect too and has become more negative than it would have been for just environmental effects. Charles River Associates model uses very general mining cost price indexes to deal with this issue (5). More work is needed to find a practical way of separating out non-environmental costs of production increases away from environmental costs increases. Another problem is that this study can only analyze the initial impact of EPA regulations. In the long run, the effect could be much different. Although more work needs to be done, the models of this study can be important in taking the first steps in understanding the impact of the environmental regulations on domestic lead and zinc mining.

The results show that the zinc and non-Missouri lead mining industries have a measurable negative reaction to the EPA regulations. This reaction is particularly important in the non-Missouri lead segment. In neither case is the magnitude of the effect anywhere near that

attributed to it by the industry. However, the impact is sizeable. Any environmental impacts on Missouri lead production were unmeasurable in our models. Missouri lead production, however, had the opportunity to design the necessary environmental protection equipment into the new facilities which is cheaper than adding the equipment afterwards as in the other mining sectors.

## CHAPTER V. PUBLIC POLICY AND ITS IMPLICATIONS

## Alternative Types of Public Policies

The government at this time uses only direct regulation to deal with the environmental issues. Given that other policy alternatives exist, it would be worthwhile to examine other alternatives that may be applied to the lead and zinc mining industry.

One possible method is to have the firms causing the externalities to internalize them - make the external costs part of the joint production decision. This internalization could be accomplished by creating a market for the externality rights, by forming one large public firm, or by Coasian negotiation. Unfortunately, these procedures have severe problems. To create a market for the externalities one would need a very narrow range of causes in a limited area with a small number of firms. This system would also require well-defined property rights and accurate measurement of the externalities. The same situation would hold true in the case of bargaining between the firms and the affected parties (as described by Coase (7)). In either of these cases, a strictly limited situation is needed for feasible applications of the techniques. The third technique, creating a public firm, would not only need a limited circumstance but it would take the production decision completely out of private hands and the market system.

A more realistic approach is the use of price incentives. This method includes the use of user charges, subsidies, and auction of

pollution rights. User charges have not yet been used by the U.S. Government. The government would charge firms for the residuals they introduce into the environment. This policy has the advantage of offering incentives to firms to find least-cost solutions, of being a certain automatic enforcement, and of being relatively sensitive to economic conditions. Being sensitive to economic conditions is important because it allows the system to be flexible enough to adjust as needed to keep the firms in accord with the economy as a whole. Disadvantages would involve high monitoring costs, lack of public support, and trying to solve the environmental issue by a piece-meal procedure. Subsidies have been used many times by the government for many purposes. If the past history of the use of subsidies is any indication, the application of this tool for environmental purposes would have several problems. Once the subsidy is incorporated into the firm's production decision, payment would have to continue even if the firm closes down. The information and administrative costs would be high. New plants might be built when they would not be otherwise if the subsidy was not used. The subsidy then could indirectly cause more environmental damage by creating an industry-wide increase in size by subsidizing firms. The auction of pollution rights is a new, interesting possibility. The government would decide on the optimal amount of externalities to be allowed (no easy task in itself) and create "rights" to be auctioned off. These rights could be dealt with in a market-like manner, leading to an efficient allocation of

resources. This approach is promising but needs additional development before it is operational.

Finally, one returns to direct regulations. This procedure is not a least-cost solution since all firms are treated the same. However, industry favors direct regulation (if some type of control is unavoidable) because of the enforcement problems the government faces. These problems are four-fold involving the uncertainty of detection, the decision to prosecute, the outcome of the judicial process, and the conflicts of interest in the regulatory agencies. The government favors direct regulation because of its quick response to standards, and it may be the only method to get a good response from industries with market power.

A possible practical alternative to direct regulations has been suggested by Baumol and Oates (4). This hybrid program would involve a combination of standards and taxes. The standards (regulations) would be used to fix limits for the allowable amounts of environmental damage as described by the regulatory body. To achieve abatement levels above the set minimum, taxes (price incentives) would be utilized. Taxes can be more economically efficient in the achievement of abatement levels over that of regulations in that regulations do not take into account the difference in plant conditions - costs in achieving pollution abatement. A tax will cause the redistribution of abatement among the firms to a least-cost solution. This program could lead to a least-cost solution. The procedure is particularly good for environmental problems

which are seasonal in nature like water flows. Caution must be used in the acceptance of any policy because of the administrative costs and problems involved, but this program could well be implemented by the government.

#### Applications to the Lead and Zinc Industry

The quantitative models have attempted to show the effect of environmental regulations on the various segments of the lead and zinc mining industry. An aspect of the models has been identification of major influences on the industry and the estimation of the degree of responsiveness of the supply of domestic ores to these factors. It is possible to utilize these models to evaluate the appropriateness and effectiveness of different policies associated with environmental protection.

The zinc industry is quite price responsive (0.78). Any policy which would affect the price of zinc will have a substantial impact on the supply of domestic ores. The government can directly influence the domestic price of zinc through three existing tools. First, the government can manipulate the tariffs on zinc related imports. A removal of the tariffs would cause a decrease in domestic prices due to the lower costs of foreign competitors. The lower prices would bring about a corresponding decrease in domestic ore supplies. Lower ore supplies would result in less environmental damage. Also, higher tariffs would support higher domestic prices, higher production, and more damage. The second

tool is manipulative of the government's stockpile. The government can easily enter the market to buy or sell zinc; if the government wishes to reduce zinc mining, it can sell zinc to lower the price. If the government desires to aid the industry because of the increased costs caused by EPA standards, it can purchase zinc to help raise the quantity demanded. The third instrument is the use of a quota. The quota in the zinc model brought about a 6% increase in domestic zinc production. This policy could offset the disadvantage domestic companies would encounter from foreign competitors who are not forced to internalize environmental costs.

A major environmental effect of the zinc industry is from the  $\text{SO}_2$  gas produced by smelters. As shown in the zinc model, smelter production has a significant influence on the amount of domestic ore produced (0.93). Therefore, any policy to control  $\text{SO}_2$  gas emissions must consider the impact on active smelter capacity and indirectly ore supplies. There are  $\text{SO}_2$  gas control policies which avoid reductions in active smelter capacity. For example, plants for recovering commercial supplies of sulfuric acid can be feasibly added to existing facilities. The value of the recovered acid may not be enough in some cases to completely pay for the plant capital costs and operations but is much cheaper than alternative clean-up equipment (20). The government can support the addition of these acid plants through incentives like tax advantages, grants, favorable loans, etc. The government can also support research into the metallurgy of non- $\text{SO}_2$  gas producing methods.

Importation of zinc is a sizeable factor in the industry and could be instrumental in environmental protection. Government policy could support the importation of zinc metal over zinc ores and concentrates to avoid many of the domestic environmental problems. This procedure only moves the external costs from the United States to foreign countries and does not really deal with the issue.

Non-Missouri lead production is similar to zinc and would react in much the same way. Yet, there are differences. Non-Missouri lead production is responsive to both lead (0.59) and zinc (-0.50) prices. Accordingly, any pricing policy for zinc will have a significant negative effect on lead output. The response is not the same for zinc (0.78) and lead (-0.38) prices in the zinc sector. Therefore, any pricing policy in one sector must consider the other sector's response. Only the magnitude of response is different for the zinc and non-Missouri lead sectors. The non-Missouri lead model shows that a quota has negative (15%) effect on ore supplies which is different from the zinc's positive effect. This difference requires that quota policies should be implemented separately for zinc and lead.

Missouri lead production is the factor that controls the domestic lead market. The empirical models show that old mines are price responsive (0.97) and new ones are not, at least in the short run. The New Lead Belt is the dominant source of ore today. Any moderate price incentive policy could be implemented with no real effect on ore supplies due to its low response to market prices. In fact, direct

regulations are probably the only way to influence Missouri lead production behavior without disrupting non-Missouri lead production. The models show that zinc and non-Missouri lead ores are very responsive to prices while Missouri lead production is not in the short-run. However, Missouri lead production can be affected through the smelter sector. If the lead cannot be smelted, it will not be mined. Any policy which would make Missouri smelters less competitive will reduce Missouri lead output. For example, policies could involve different types of taxes on output.

Policies to control the actual amount of mining can be reliably instituted by the government through two existing instruments. These instruments can avoid the uncertainty implied for the later stages of recovery. The instruments are the severance tax and the control over public lands. Unfortunately, under the present situation, the joint use of these instruments would involve cooperation between various state governments and the federal government. The severance tax could raise the per unit marginal costs of mining to the level indicated by the social supply schedule. This situation would lead to an optimal social extraction level. In much the same way, the federal government can control the amount of mining done on public lands. Since public lands make up a large percent of potential mining sites, government control can directly make the trade-offs between the environment and needed mineral resources at the optimal rate for society. Together,

these policies would be fairly complete in their coverage of mining operations. Another means of reducing mining is through incentives for recycling of lead and zinc scrap, especially lead scrap. Lead scrap is becoming more important in the industry and could greatly reduce the need for "new" lead. This importance is very evident in the amount of lead recovered from old batteries with very little loss of material as market prices rise. Incentives could include removal of higher rail rates for scrap than ores, tax breaks for recycling plants, taxes on "new" lead, and tax credits for private firms that recycle lead.

In conclusion, it should be mentioned that the lead and zinc industry have made EPA deadlines so far. Some slow-downs in the industry, especially involving smelter production, have been blamed on the standards. Evidence, however, suggests that reduction in subsidies and protection from foreign competitors are more likely the causes. On the whole, despite the opposition to the regulations, the industry has developed new approaches and techniques and has incorporated the additional costs more readily than other industries. It would appear that the EPA regulations can be imposed on the lead and zinc industry with only minor supply disruptions if government policies are employed. Trade-offs between base metal production and environmental amenities must be made. At the present time, these trade-offs can only be accomplished through government implementation of policies.

## CHAPTER VI. CONCLUSION

This study has applied econometric models to the estimation of the effect of environmental regulations on domestic lead and zinc ore supplies. The effect is measurable and significant but not of dominate proportions in the industry. Other results from the models are the importance of market prices for older mines, the impact of import controls on the various industry sectors, the significance of vertical integration in the extractive industry, and the rather minor role price plays in the extraction of lead from the New Lead Belt. These model results are then used as guidelines for an analysis of possible public policies and their likely effect on the industry.

More work is needed on the quantitative models to better understand the effect of environmental regulations on the domestic lead and zinc mining industry. This study uses a dummy variable for environmental regulations with technology and factor costs assumed constant over the relevant time period. For more sophisticated models, technology and factor costs should be involved. Variables need to be developed that can introduce these factors into the industry models. Possible techniques could be in the form of an index for factor costs used like a price index and a proxy for technology using an observable and measurable condition. These concerns are beyond the scope of a study of this nature.

It would be instructive to develop an environmental standards variable that is more indicative of the direct year-to-year variable

impact on the industry then the results of the simple constant dummy variable. Another refinement would be the breaking down of the EPA standards into various segments like SO<sub>2</sub> gas production, acid mine drainage, tailings discharge, etc. and dealing with each independently. In the same direction, a model for smelter production would be a worthwhile tool as this study has shown the importance of the links between mining and smelting.

Finally, a model that can analyze the effect environmental regulations have on Missouri lead ore output needs to be developed. An understanding of the EPA effects in initial mining decisions and new capital investments is of great importance for future development. Also, Missouri lead mining should be continuously monitored to learn about the environmental regulations impacts as a mining site ages.

A major empirical problem in developing quantitative models for the domestic lead and zinc mining industry is government intervention. The purpose of this study is to analyze the effect of one type of government intervention, EPA regulations, on the industry. However, the government is also a factor in many other ways. The government regulated the prices of silver and gold, by-products of base metal mining, for years. The government's stockpiling policy has always been very sporadic. Finally, the enactment of various tax laws and import controls introduces major random influences into the set.

A second problem is the uncertain nature of available ore supplies. Unlike other industries, the mining industry can be greatly altered by

the sudden discovery of new orebodies. By its very nature, there is no way to accurately predict when or how much new ore will be found. New uncertainty has been introduced by the political issues on whether extraction will be allowed or not after ore sources have been found. Until radically new technology is developed, these conditions will exist.

The importance of environmental protection will continue to grow as does man and his technology. The pressures to increase industrial growth and income will force a trade-off between the environment and the resources it can supply. The only possible way this trade-off can be done efficiently and at the level society desires is through government policies. However, before the government can make a correct decision on the type of policy to pursue for this purpose, the government must have an accurate knowledge of the effect of its decisions. Supplying this knowledge is the purpose of this study's models. The lack of work in this area is amazing and unfortunate. The government, and by extension society, is developing and using policies with no understanding of their impacts and effects. Unhappily, decisions in this area of resource development are for all practical purposes irreversible. Information is the basis for any type of optimal behavior in the use of our environment and the recovery of its mineral resources. The lack of information can only bring future problems.

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APPENDIX A: TYPICAL ZINC AND LEAD MINING  
AND MILLING COSTS

Situation (6)

Room and Pillar System-Flat Bedded Deposits-8.90 ft. Thick Ore  
Bodies-Vertical Shaft Access-500-1,000 Feet Deep-Dumping 2,000-  
5,000 gpm. Water-Capacity-5,000 Tons/Day=1,500,000 Ton/Year-  
\$5,000,000 in Mines Investment-\$15,000,000 in Mill Investment.

Table 5. Costs<sup>a</sup>

Mining Costs	\$/Ton Ore
Underground Development	0.29
Mining	1.58
Transportation	0.80
General Expense	0.60
Surface	0.03
Transportation to Mill	0.10
Depreciation (10 years)	0.29
Interest Charges (6%)	<u>0.19</u>
	3.88
Milling Costs	
Crushing	0.08
Conveying and Screening	0.10
Fine Grinding	0.35
Flotation and Thickening and Filtration	0.45
Concentrate Handling	0.03
Tailings Disposal	0.08
Water Supply	0.06
Misc. - Maintenance	0.20
Supervision	0.20
Depreciation (10 years)	0.86
Interest Charges (6%)	<u>0.56</u>
	2.97
Grand Total	6.85 P.T. Ore

<sup>a</sup>Source: based on (6).

## APPENDIX B: LEAD AND ZINC DATA

Table 6. Zinc

Year	QZ <sup>a</sup>	PZ <sup>b</sup>	PL <sup>c</sup>	QL <sup>d</sup>	SM <sup>e</sup>	DQ <sup>f</sup>	DE <sup>g</sup>
1953	495	14.1	17.4	328	916	0	0
1954	380	13.9	18.3	322	802	0	0
1955	515	13.9	17.2	338	964	0	0
1956	542	14.0	16.6	353	984	0	0
1957	532	13.2	17.3	338	986	0	0
1958	412	13.0	15.3	267	781	1	0
1959	425	13.7	14.5	256	799	1	0
1960	435	15.1	14.0	247	800	1	0
1961	464	14.0	13.1	262	847	1	0
1962	505	14.1	11.7	237	879	1	0
1963	529	14.6	13.5	253	893	1	0
1964	575	15.5	15.5	286	954	1	0
1965	611	15.2	16.8	301	994	1	0
1966	573	14.5	15.1	327	1025	0	0
1967	549	13.9	14.0	317	938	0	0
1968	529	13.0	12.8	359	1021	0	1
1969	553	13.0	13.1	509	1041	0	1
1970	534	12.3	12.6	572	878	0	1
1971	503	13.9	12.0	279	766	0	1
1972	478	15.7	12.8	619	633	0	1
1973	479	15.3	12.0	603	584	0	1
1974	500	19.2	12.0	664	555	0	1
1975	469	22.7	12.5	622	438	0	1

<sup>a</sup>Domestic zinc ore supplies in 1,000 tons.

<sup>b</sup>Indexed domestic producer price for zinc metal per pound.

<sup>c</sup>Indexed domestic producer price for lead metal per pound.

<sup>d</sup>Domestic lead ore supplies in 1,000 tons.

<sup>e</sup>Zinc smelter output in 1,000 tons.

<sup>f</sup>Dummy for import quota.

<sup>g</sup>Dummy for environmental regulations.

Table 7. Non-Missouri lead

Year	QO <sup>a</sup>	PL	PZ	DLM <sup>b</sup>	DQ	DE
1953	202	17.4	14.1	0	0	0
1954	197	18.3	13.9	0	0	0
1955	213	17.2	13.9	0	0	0
1956	229	16.6	14.0	0	0	0
1957	212	17.3	13.4	0	0	0
1958	154	15.3	13.0	0	1	0
1959	151	14.5	13.7	0	1	0
1960	135	14.0	15.1	0	1	0
1961	163	13.1	14.0	0	1	0
1962	176	11.7	14.1	5	1	0
1963	173	13.5	14.6	3	1	0
1964	166	15.5	15.5	0	1	0
1965	167	16.8	15.2	0	1	0
1966	195	15.1	14.5	0	0	0
1967	164	14.0	13.9	0	0	0
1968	146	12.8	13.0	0	0	1
1969	154	13.1	13.0	0	0	1
1970	150	12.6	12.3	4	0	1
1971	149	12.0	13.9	3	0	1
1972	130	12.8	15.7	0	0	1
1973	116	12.0	15.3	0	0	1
1974	102	12.0	19.2	0	0	1
1975	106	12.5	22.7	0	0	1

<sup>a</sup>Domestic non-Missouri lead ore supplies in 1,000 tons.

<sup>b</sup>Dummy for Missouri lead industry labor strikes.

Table 8. Missouri lead: 1953-1966

Year	QM <sup>a</sup>	PL	DLM	TM <sup>b</sup>
1953	126	17.4	0	1
1954	125	18.3	0	2
1955	125	17.2	0	3
1956	124	16.6	0	4
1957	126	17.3	0	5
1958	113	15.3	0	6
1959	105	14.5	0	7
1960	112	14.0	0	8
1961	99	13.1	0	9
1962	61	11.7	5	10
1963	80	13.5	3	11
1964	120	15.5	0	12
1965	134	16.8	0	13
1966	132	15.1	0	14

<sup>a</sup>Domestic Missouri lead ore supplies in 1,000 tons.

<sup>b</sup>Time trend (1953=1)

Table 9. Missouri lead: 1967-1975

Year	QM	CM <sup>a</sup>
1967	153	180
1968	213	270
1969	355	403
1970	422	425
1971	430	445
1972	489	465
1973	487	475
1974	562	475
1975	516	475

<sup>a</sup>Pig-lead smelter capacity in Missouri in 1,000 tons.