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Center
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# DEMAND CHARTS - TOOLS FOR PLANNING

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## INTRODUCTION

Does a new manufacturing process make economic sense? What revenues can be expected from a new product? Is the price/volume relationship for a new product likely to be elastic or inelastic? What is the best way to move in the price/volume plane to increase revenues; backward toward raw materials, or forward toward systems? Studies of demand charts can help to answer all of these questions.

The importance of demand charts in economics is attested by the substantial amount of discussion that is devoted to them in textbooks (1). However, they are but rarely mentioned in discussions of research planning. This paper is an attempt to redress this neglect by describing some of their properties, and their considerable utility. They will be called "charts" here, instead of the more usual "curves", because data for various related products will be discussed rather than single commodities. Such charts are also called "price-volume' charts.

Demand charts relate how much of given products will be bought by customers at various price levels. Often the quantity of product is expressed as weight per year, but it may also be expressed as units per year, or some measure of utility per year. Let us call this quantity parameter, Q. Price is expressed as dollars per unit quantity; call it P. Then the product of these two parameters, PQ gives the yearly revenues, R as dollars per year.

Closely related to demand charts are supply charts which describe how much of a given product will be offered to the marketplace by producers at various price levels. If the supply and demand charts are plotted together, the intersection of their correlation curves is the equilibrium point for the particular class of item, material, or amount of utility. It is also one point on a demand chart in another marketplace. Thus, there is a hierarchy of demand charts. The theory of their dependence on time, which is closely related to forecasting, has been discussed by Agnew (2).

## PROPERTIES

As an example, consider the chart for magnetic alloys shown in Figure 1. These alloys are of the "soft" variety which means that they can be easily magnetized and demagnetized. This behavior makes them desirable for the cores of transformers, and for many other applications. From a purely technical viewpoint the cobalt alloys would make the best transformers, but their high prices limit their use to the volume indicated in the figure. Silicon steels make less good transformers, but are much cheaper than the cobalt alloys. Therefore, they are used in much greater volume. Notice that this demand chart is not continuous, but consists of a set of discrete points correlated by a regression line.

One important property of demand data that is illustrated by Figure 1 is that volume virtually always increases with decreasing price. It also illustrates that most markets are well-behaved in the sense that they are governed by a simple relationship between price and volume.

For planning purposes, one of the most important, and yet very simple, properties of a demand chart is that it is exclusionary. That is, the marketplace it describes allows products to be introduced at points lying below the line on the P-Q plane, but not above it. No customers will be found at points above the curve. This allows a quick determination of what the maximum reasonable price is likely to be for a new product if a given volume of sales is desired. Or, at a given price, what maximum volume can reasonably be expected. Care is required, of course, to assess whether the appropriate demand chart is being used.

If a demand chart is plotted using log-log coordinates, then straight lines of constant annual revenues can be superimposed on the same chart. The constant revenue lines have slopes equal to minus one. With the revenue lines in place, the revenue magnitudes can be quickly determined by inspection.

The elasticity of the market can also be seen readily. It is defined as the reciprocal of the slope times minus one. It is neutral if the correlation line has a slope of minus one. In this case, it is parallel to the constant revenue lines, and changes of prices have no effect on total revenues. If the slope is much less than minus one, the market is elastic and small price changes tend to lead to large revenue changes (but gross margins may decrease if production costs do not move in concert with price changes). Inelastic markets are those for which the slope of the demand curve is greater than minus one. Here a drop in price will produce smaller total revenues. Furthermore, raising the price is dangerous for this situation because of the exclusionary property of the demand curve. There may well be no market at all at a higher price.

It should always be kept in mind, of course, that demand curves are correlation lines for the discrete points that represent demand/supply equilibria. The stabilities of these equilibria can have an important effect on the properties of a given market situation. In other words, these curves should be interpreted with appropriate skepticism, and common sense. They can be very useful, but should not be followed blindly.

## EXAMPLES

Biotechnology - About five years ago there was much enthusiastic speculation in the literature about making chemicals through biological processes instead of the established synthetic chemical methods. In the preliminary phase of planning a research program, I investigated the sensibility of these speculations by constructing a demand chart for a variety of chemicals that could be made biologically if there were an incentive to do so. To minimize personal bias, I used data that were published by enthusiasts of the U.S. Office of Technology Assessment. Figure 2 shows the resultant chart. Although some of the points fall well away from the regression line, the overall correlation of the data is quite high as indicated by the correlation coefficient of -0.90.

To test the feasibility of making these chemicals biologically, one can draw a horizontal line on the chart at a level that represents the cost of fermentation. The prices on the chart are selling prices, so the equivalent cost of fermentation would be at least about one $/#. All of the points on the chart to the right of aspirin lie below this cost level. In other words, virtually all commodity and intermediate special chemicals cannot be made economically via fermentation. In a few cases, such as ethanol, the situation is marginal and swings one way or the other depending on the relative costs of raw materials, tax credits, and the like.

This simple use of a demand chart allowed the contrarian conclusion to be quickly reached that it was very unlikely that a new industry was about to emerge based on biological chemical processing. Because of the local scattering of the data points, this situation could not be assessed as clearly without the chart. It provides a much needed perspective by showing the relationships between the individual points, and by correlating data when particular values differ by orders of magnitude.

In addition to indicating which types of chemicals are accessible to bioprocessing, the demand chart indicates the sizes of the revenue streams that could be expected. The one dollar per pound level intersects the regression line at about 20 MM$/yr. Thus no single product will create more revenues than this if it is made by fermentation. Another way of saying this is that fermentation as a process could not lead, of itself, to large markets. So a prudent planner should look elsewhere if he will not be satisfied with small markets.

Ceramics - Currently, there is much interest in ceramic materials. They offer a number of intriguing technical characteristics for the construction of advanced electronic, mechanical, and optical devices. There is also much talk of large emerging markets. This can be put into perspective by considering some demand charts for ceramics.

A demand chart is given in Figure 3. The data points refer to raw materials that are the principal inputs to the indicated product areas. The correlation line has a coefficient of -0.83 associated with it, so it represents the data well. The reciprocal of its slope is 1.9 which is moderate. The numbers in parentheses give the annual revenues for each industrial category (in units of 100 MM$). The sum of the revenues is 1.8 MMM$ which is not very large. It is dominated by glasswares and refractories which comprise 78% of the total.

Only 6.1% of ceramic raw materials go into electronic and other technical ceramics. After these have been upgraded into products they gain an order of magnitude in value as indicated in the figure. Then their value becomes about 1.1 MMM$ which is quite small if they are viewed as commodities. By comparison, the value of annual steel consumption is nearly one hundred times greater. Thus it should not be surprising that research budgets in the ceramics area have not been large; and have not tended to be spent by the producing industry. The burden for doing research has been passed on to users.

From the user viewpoint, a particular ceramic material or component may play a critical role in the overall performance of a device. As a result it behooves the user to pay a premium price, or to invest the funds to develop the relatively small market segment that is critically needed by the user. This approach has long been used by the military establishment.

Ceramic materials increasingly play a variety of roles in integrated materials systems. In this case the utility value of the materials may rise markedly. This is illustrated by comparing the values of silica in some of its forms, along with gold for comparison:

| FORM | APPROXIMATE COST ($/#) |
|---|---|
| Sand | 0.005 |
| Silica powder | 0.003 |
| Bulk fused silica | 0.20 |
| Silica components | 20.0 |
| Integrated chips | 2000.0 |
| Gold | 5000.0 |

In the case of integrated chips, the average cost for the whole chip is given because it is not possible to separate out the cost of the silica insulation layers; nor is it possible to separate out the value of the silica in terms of its utility. The high average cost per pound indicates, however, that sophisticated knowledge of the properties and processing methods for these materials is much more valuable than the material itself.

Batteries - This brings the discussion to pricing relative to utility, rather than pricing based on weight (or volume). In general, price schedules for materials are shifting increasingly toward a utility basis as they become integrated into composites, devices, and components. This shift is fundamental because it is based on the fact that the final form of the material requires increasing amounts of information for its specification (3).

As an example, consider portable electric power sources (batteries). These are integrated materials systems with a quite simple function. If one tries to correlate their prices and quantities in terms of numbers of units (or weights) the result is poor. However, if their utility is used as the basis, the correlation is excellent as illustrated in Figure 4. It is assumed that each type of battery produces enough electric power (watts) to satisfy its scope of applications, so its utility can be measured in terms of energy (watt-hours). The result is an excellent correlation between the energy price and the amount of portable energy purchased. This latter depends on the cycle-lives of secondary batteries. The correlation coefficient of -0.96 is very high.

The elasticity parameter for batteries is 1.3 which means that the correlation line is relatively parallel to the constant revenue lines. Thus, the overall market is only slightly elastic. Some portions of the market, such as the competition between sealed lead-acid and automotive lead-acid batteries may be quite elastic, however.

For planning the entry of a new battery into this market, the exclusionary property of this chart, plus the low elasticity that it indicates, should make it quite useful.

Engineering Polymers - An example of a highly elastic market is provided by engineering polymers at the level of neat resins. Figure 5 presents this data for eleven resins. It may seen by inspection that small price changes have very large effects on consumption. This should not be accepted too literally because the applications of these polymers are quite varied, and this influences the amounts consumed. Nevertheless, it is clear that a strong barrier to the prices of these resins exists between one and four dollars per pound. Prices above this range result in negligible consumption.

Organic Chemicals - A market that is related to polymers but which is much more broad is this one. It provides another illustration of the importance of having the right units for the price and quantity parameters. If the data for 27 leading organic chemicals are plotted using dollars per pound for P, and pounds per year for Q, the resulting correlation coefficient is -0.57. However, if dollars per mole is used for P, and moles per year for Q, then a much better correlation is found having a coefficient of -0.76 (Figure 6). It is gratifying that the more natural units win out over arbitrary historical ones.

A question of considerable interest ten or so years ago was whether chemicals could be produced photochemically using lasers. Since laser photons cost 0.2-0.5 $/mole, Figure 6 shows that direct laser photochemistry will not yield a viable manufacturing process for common chemicals. Of the points in the figure, only the one for adipic acid falls close to the required range. In order to get into the range, high quantum yields or other multiplying effects are needed, perhaps as the result of an appropriate free radical reaction. Such cases do exist and are being explored by research workers.

The trend line in Figure 6 can be extrapolated to estimate some of the coarse features of the markets in which photochemistry might compete. The price might be 0.90 $/mole for a quantity of about 100 MMmoles/yr. This corresponds to annual revenues of about 90 MM$/yr. Thus laser photochemistry is very unlikely to be used for making commodity chemicals, but may well be used for making specialties. This same conclusion has been reached by other people using various approaches. The point here is that such conclusions can be reached quickly, and reliably, by means of demand charts.

Radioisotopes - In the chemical field, specialties are likely to have less elasticity than commodities. This is illustrated here by the case of radioisotopes which require special methods for production, are expensive, and are sold in very small quantities (except for reactor fuels). Data for them, collected by J. Yardley (4) are presented in Figure 7. The slope of the regression line is quite close to minus one which corresponds to neutral elasticity. This small elasticity is comparable to the low elasticity for the inorganic chemicals that constitute raw material for electronic ceramics.

Structural Metals - In this case prices and consumption levels are unusually closely correlated as may be seen in Figures 8 and 9. In the former the units for P and Q are in terms of pounds, while in the latter they are in terms of cubic inches. In both cases the correlation coefficients are -0.99 for the log-log linear regression lines. Thus the exclusionary boundary is very sharply defined, as is the amount of market elasticity.

For comparison, the regression line for engineering polymers from Figure 5 is overlaid on Figure 9. The large price differential between the two correlations accounts for the rapid penetration of traditional metals applications by engineering polymers. For applications in which elastic stiffness is important, the price differential may be markedly reduced (or reversed). Nevertheless, the nature of the competition is clearly stated by Figure 9.

## SUMMARY

For the various examples that have been presented here, the elasticity parameters are summarized in Figure 10. In addition, an estimate for automobiles is included for comparison. Notice that none of the values lies less than unity, so none of these markets is inelastic. Only highly specialized, or "vanity", markets are likely to be inelastic.

The average elasticity is 2.3, while the spread ranges from 1.0 to 6.1. Since the elasticity is a logarithmic derivative, the observed average for this elasticity means that decreasing the price by a factor of 3 corresponds (roughly) to increasing the quantity consumed by a factor of 10. For engineering polymer resins the effect is much larger than this, while for raw ceramics for electronics it is three times smaller.

## ACKNOWLEDGMENT

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## REFERENCES

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(2) C.E. Agnew "The Concept of Equilibrium and Its Use in Demand Forecasting" Tech. Forecasting and Social Change <u>8</u>, 23 (1975).

(3) J.J. Gilman "Materials Processing: Opportunities and Challenges" Jour. Metals <u>51</u>, Feb. 1972.

(4) Data collected by James Yardley, presented by M. Berry in <u>Future sources of Organic Raw Materials</u>, Pergamon Press (1979).

## FIGURE CAPTIONS

FIGURE 1 - Demand chart for soft magnetic materials. Data refer to U.S. consumption in 1977.

FIGURE 2 - Selected organic chemicals that might be made by fermentation. Data from "Impacts on Applied Genetics" published by U.S. Congress, Office of Technology Assessment (1981).

FIGURE 3 - Consumption of raw materials by various segments of the U.S. ceramics industry in 1980. The numbers in parentheses refer to annual revenues in units of 100 MM $. The data are from "Ceramic Raw Materials - North America - 1981" published by C.H. Kline & Co., Inc. Key to the letters is:

| | |
|---|---|
| A - Glasswares (7.5) | E - Electronic waves (0.8) |
| B - Structural clays (0.7) | F - Abrasives (0.2) |
| C - Refractories (6.5) | G - Enamel waves (0.9) |
| D - White waves (1.0) | H - Other technical (0.3) |

FIGURE 4 - U.S. market for primary and secondary batteries in 1981. Data collected by J.N. Gleason (Amoco Corporation).

FIGURE 5 - Price versus consumption for a dozen engineering polymers in 1984.

FIGURE 6 - Demand chart for 27 major organic chemicals plotted on a per mole basis. Data courtesy of K.V. Reddy (Amoco Corporation).

FIGURE 7 - Data for radioisotopes collected by James Yardley; see reference (4).

FIGURE 8 - Price versus consumption for the principal structural metals in the United States (1980). Data were compiled by D.E. Honaker from the <u>Engineering and Mining</u> Journal (March 1981).

FIGURE 9 - Same as Figure 7 with the units converted to volumetric basis.

FIGURE 10- Comparison of elasticity parameters for various markets.

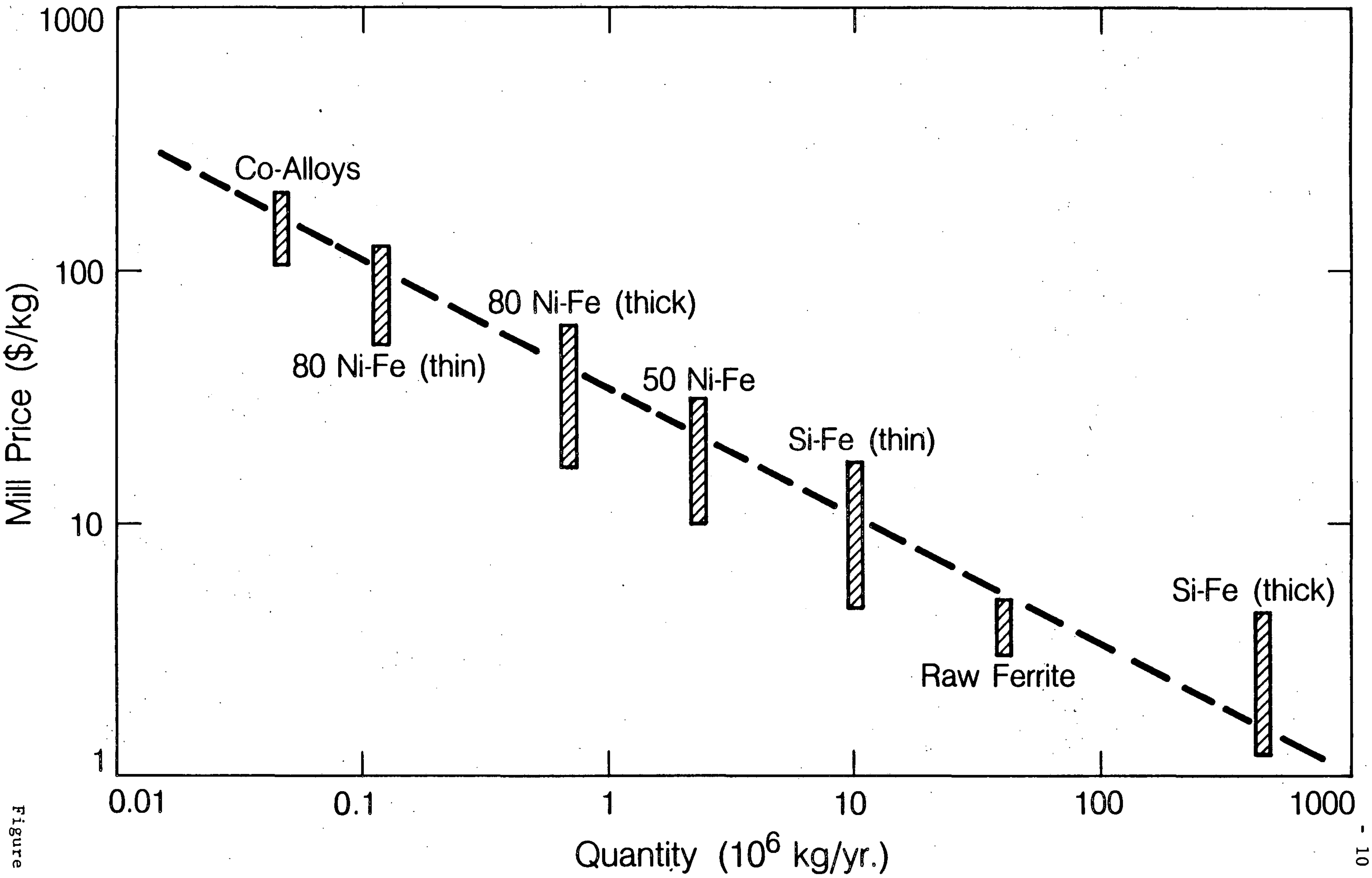
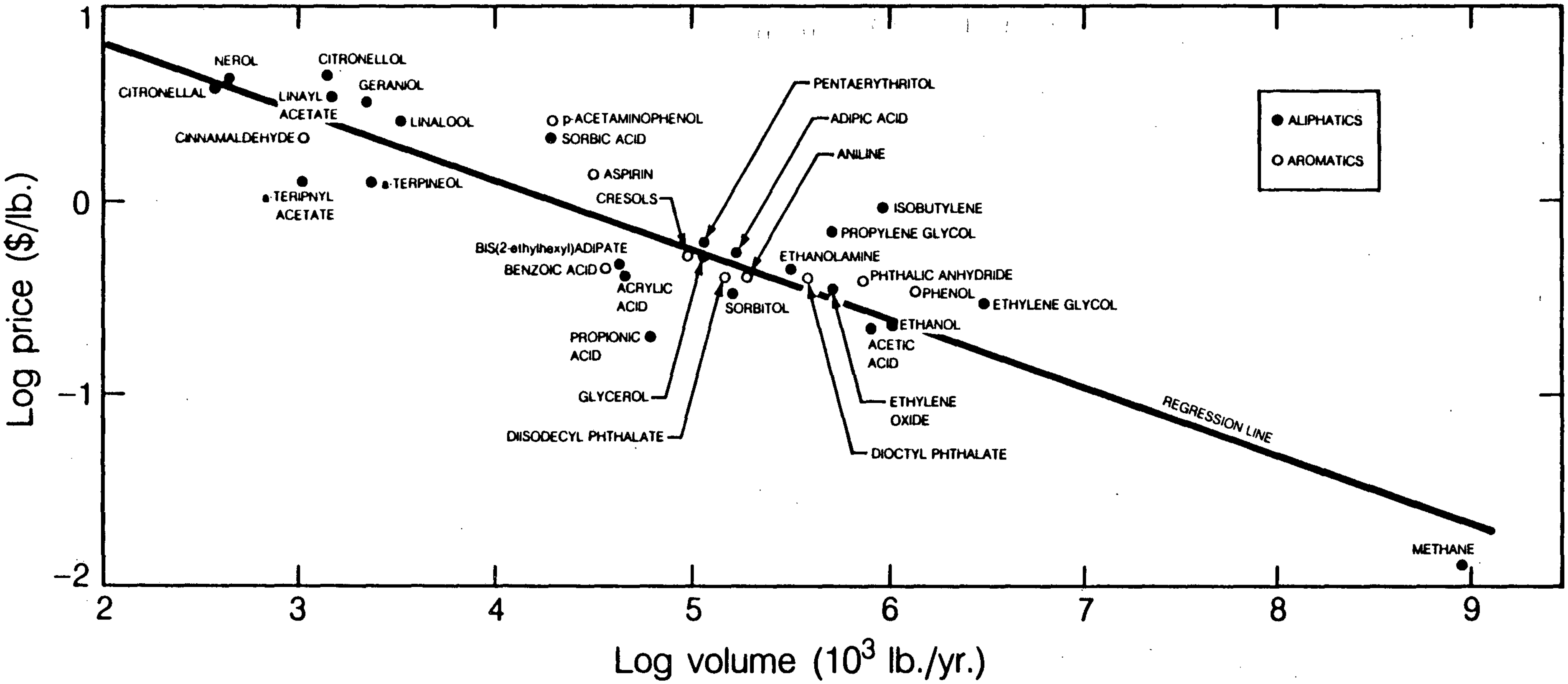


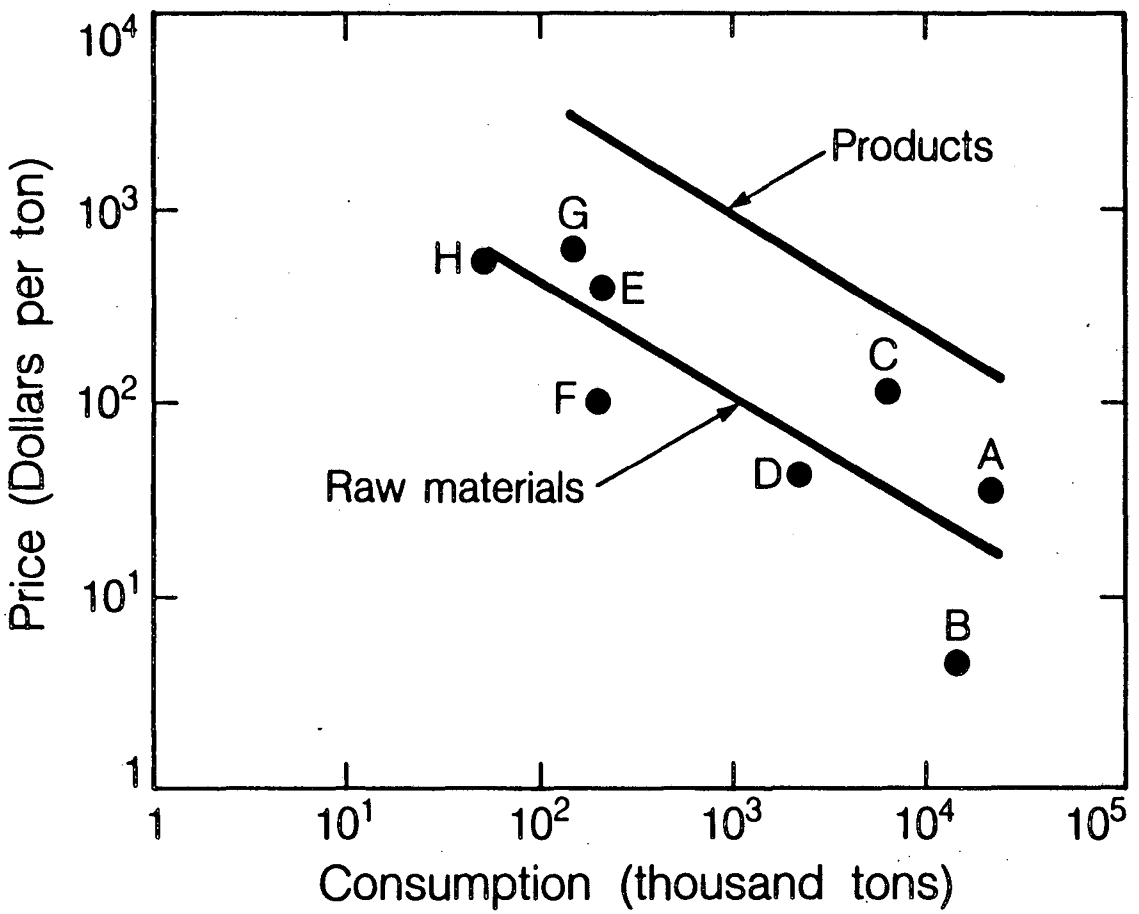
Figure 1

XBL 855-9989



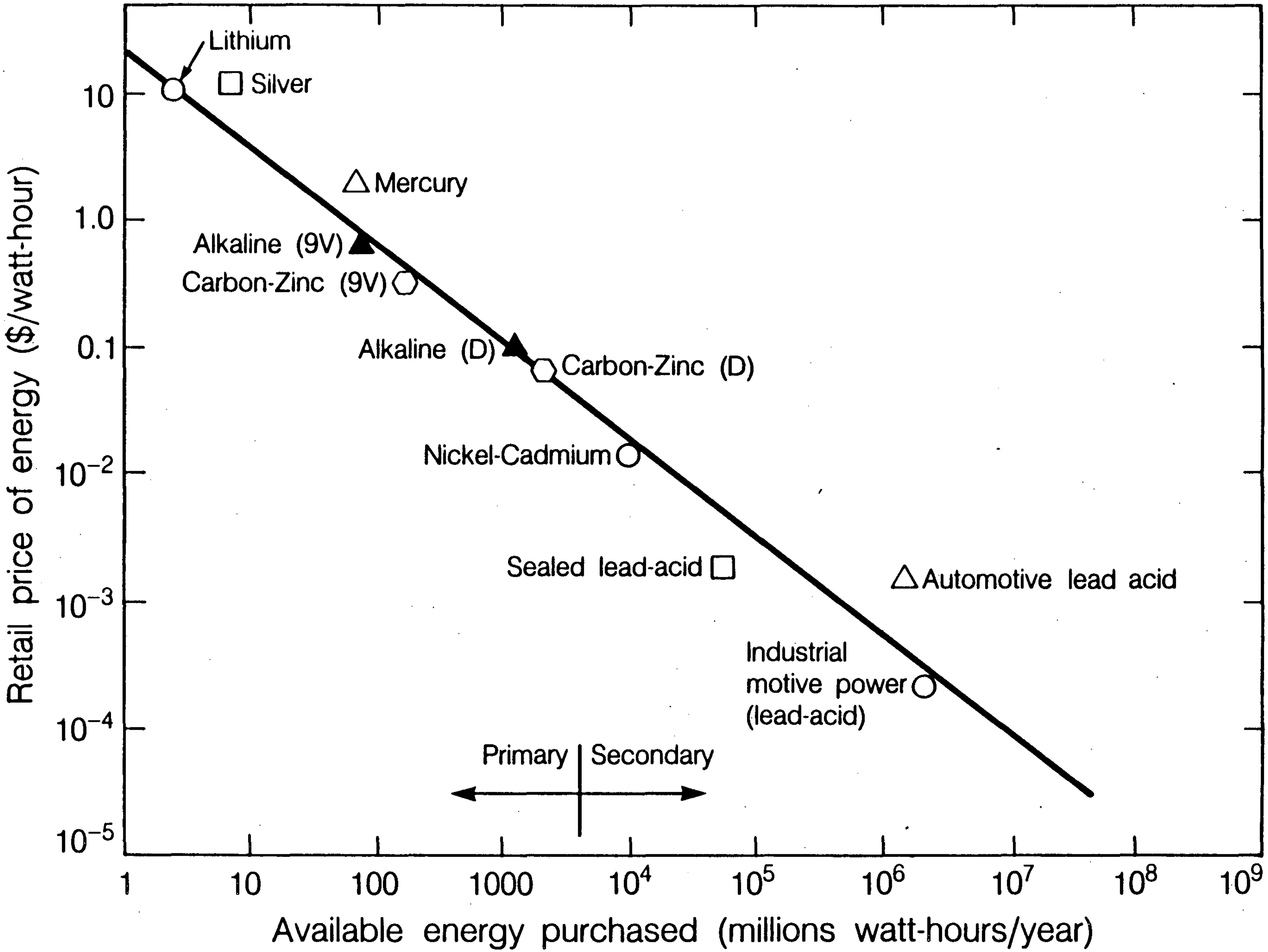
XBL 855-9988

Figure 2



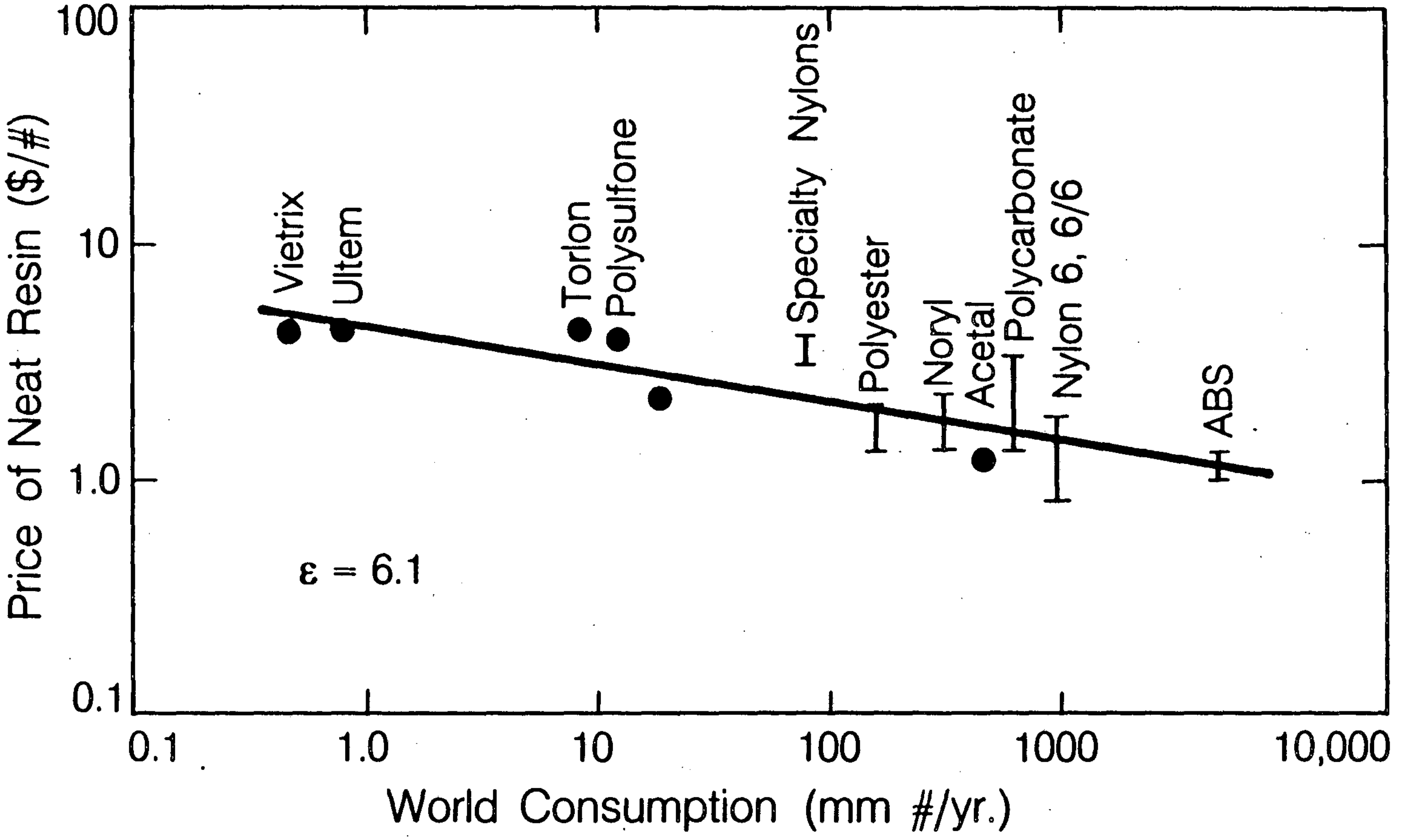
XBL 855-9990

Figure 3



XBL 855-9991

Figure 4



XBL 855-9987

Figure 5

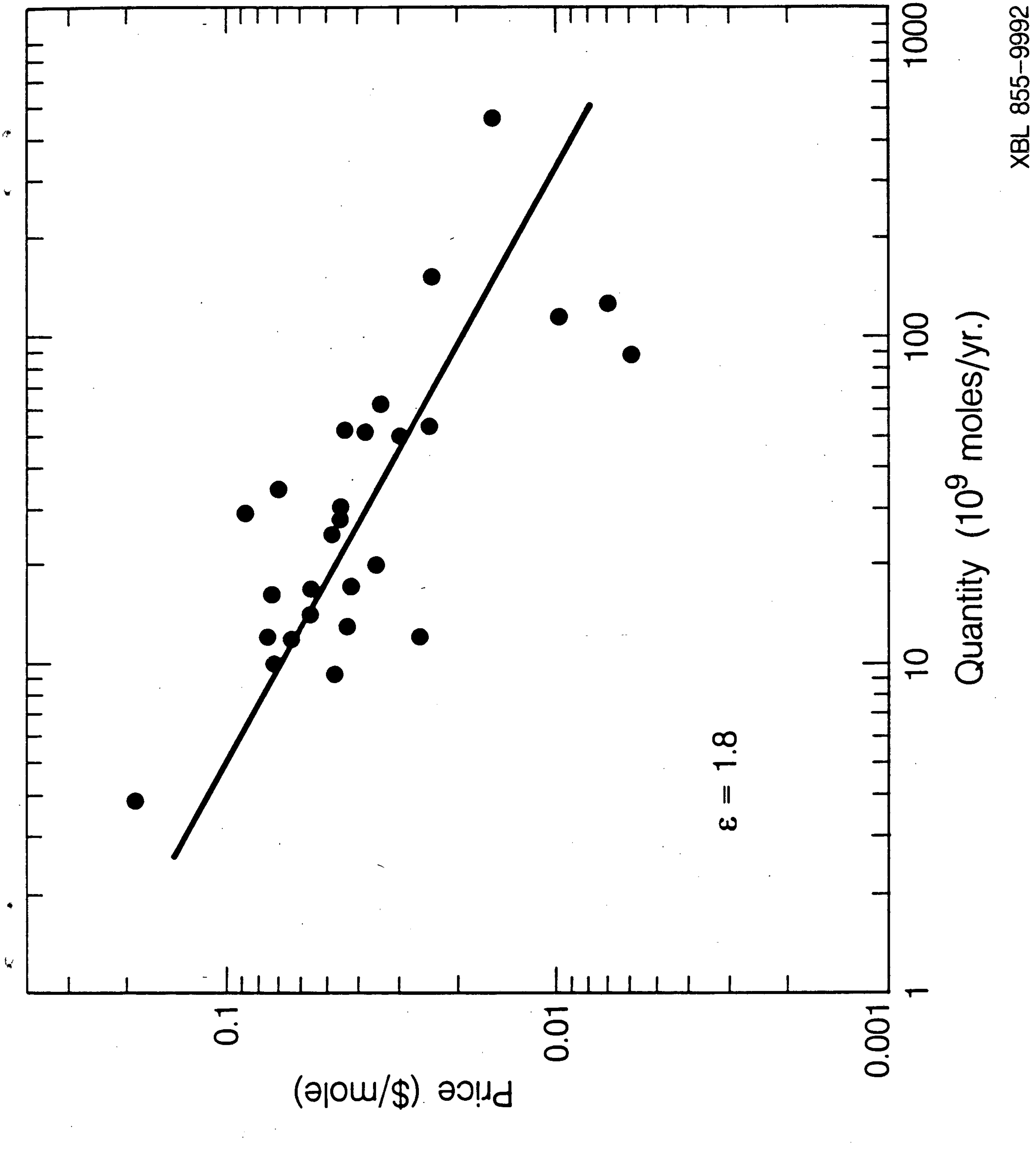

Price ($/mole)
0.1
0.01
0.001
1
10
100
1000
Quantity ($10^9$ moles/yr.)
ε = 1.8
XBL 855-9992

Figure 6

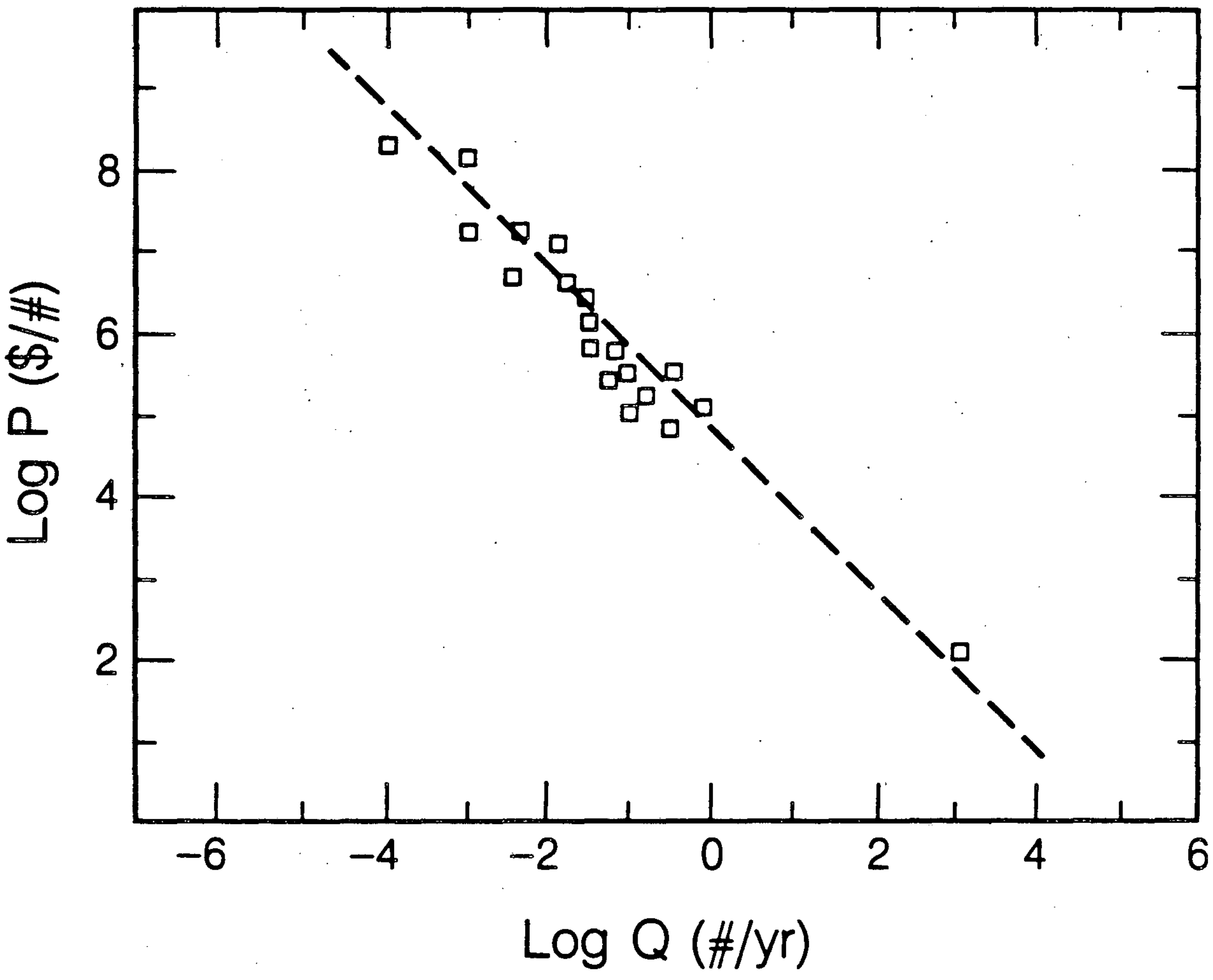


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Figure 7

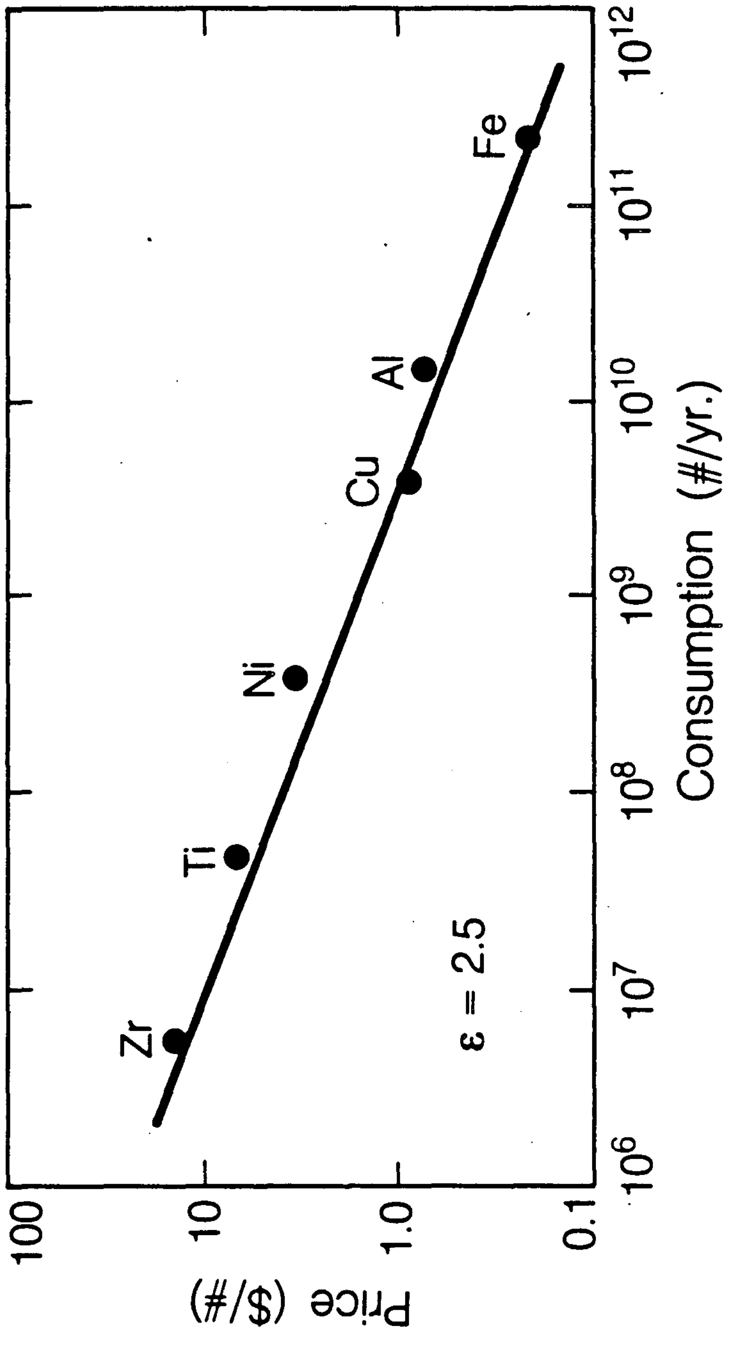

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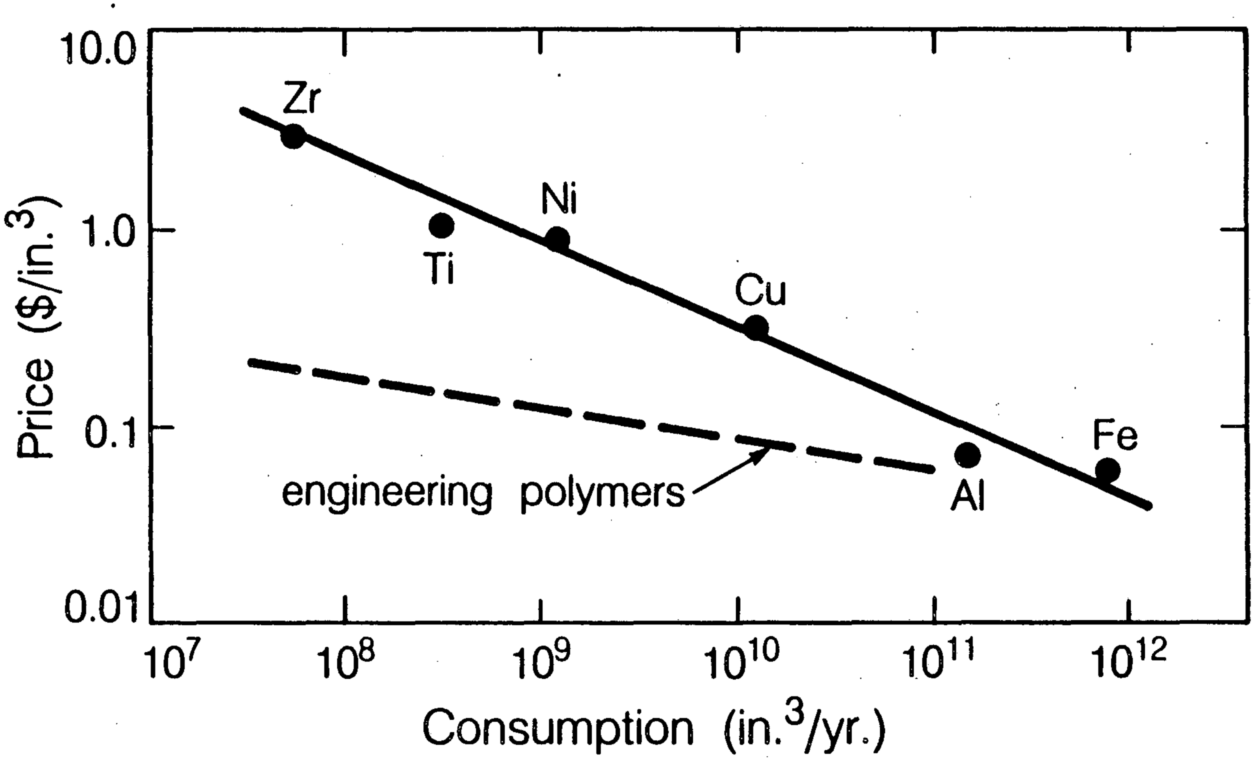
Figure 8



XBL 855-9994

Figure 9

| MARKET | ε |
|---|---|
| **Chemicals** | |
| major organics | 1.8 |
| candidates for biotechnology | 2.8 |
| engineering polymer resins | 6.1 |
| radioisotopes | 1.0 |
| **Metals** | |
| structural | 2.5 |
| soft magnetic | 2.0 |
| **Ceramics** | |
| overall raw materials | 1.9 |
| raw materials for electronics | 1.0 |
| refractory bricks | 2.2 |
| **Devices** | |
| batteries (portable electricity) | 1.3 |
| automobiles (approx.) | 3.0 |

XBL 855-9986A

Figure 10

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