WORKING
PAPERS

THE MINIMUM OPTIMAL STEEL PLANT AND THE SURVIVOR TECHNIQUE OF COST ESTIMATION

Robert P. Rogers

WORKING PAPER NO. 197

August 1992

BUREAU OF ECONOMICS
FEDERAL TRADE COMMISSION
WASHINGTON, DC 20580

The Minimum Optimal Steel Plant and the Survivor Technique of Cost Estimation

by

Robert P. Rogers

Federal Trade Commission, Washington D. C. 20580

August 1992

The survivor technique is used to examine economies of scale in the steel industry, and the results are compared to an earlier engineering approach study by Tarr. Specifically the paper focuses on the conventional integrated steel mill of over 1 million tons a year. The results are consistent with Tarr's estimate of a steel mill Minimum Optimal Scale of 6 million tons a year.

I. Introduction

Economists have long been interested in ways to determine the relationship between plant or firm size and efficiency as reflected by average cost. In many industries economies of scale are so large relative to market demand that there is room for only a few firms of efficient size. Consequently, in antitrust and regulation, information about the size of the efficient plant and/or firm is important. As with many empirical issues, several methods for estimating this cost-size relationship exist, and testing whether the different methods are consistent with each other is important. The three most commonly used methods are econometric cost curve estimation, the engineering approach, and the survivor technique. In this paper, the survivor technique is compared with a particular engineering approach estimate.

Both the survivor technique and the engineering approach use the concept of Minimum Optimal Size or MOS. For many industries, increases in plant size lead to decreases in average cost; these decreases are called economies of scale. The MOS, the key concept in studying scale economies, is defined as the smallest plant (in output or capacity) for which the economies of scale have, for all practical purposes, been exhausted. Thus, if a particular plant has MOS capacity, a larger plant would not have appreciably lower average cost.

Tarr (1977 and reported in 1984) used the engineering approach to estimate the MOS for conventional integrated steel plants in the middle 1970s. The time that has elapsed since the Tarr paper was written gives us an opportunity to use the survivor technique to test his engineering approach estimate. This procedure follows the advice of the late George Stigler (1958), the primary developer of the technique; he stated "implicitly all judgments on economies of scale have always been based directly upon, or at least verified by recourse to, the experience of survivorship."

The next section discusses the major cost estimation techniques. Section III gives some background on steel. Section IV applies the survivor technique to the steel industry and compares the results to Tarr's estimate, while Section V concludes the paper.

II. Methods of Estimating Economies of Scale and the Minimum Optimal Scale (MOS)

The three most commonly used methods of estimating economies of scale are econometric cost curve estimation, the engineering approach, and the survivor technique. With the first method, the output and cost data for the relevant economic units are used to estimate an econometric relationship between total or average cost and output. However, there are problems with measuring various components of cost such as normal profits and the cost of capital (see Fisher and McGowan (1983), Saving (1964), and Friedman (1955)). Nevertheless, econometric cost studies in a variety of industries have been done (See Christensen and Greene (1976) and Friedlaender et al. (1983)).

With the engineering approach, engineers or other industry experts are asked to estimate the size of the MOS plant in a given industry. One problem with this approach is that the efficient plant size may be a function of input availability and prices. Often different levels of input prices will lead to different size plants having the lowest costs. Different assumptions on input cost levels will lead to radically different MOS sizes for certain industries. In some countries the cost of labor is relatively cheap, and the cost of capital is relatively high. In many industries such as farming, efficient labor-intensive firms are smaller than firms producing the same product with a more capital-intensive process. A second problem with the engineering approach is that an engineer usually conceives a plant with the latest technology, even in situations where older plants will survive quite nicely in the particular economic environment. Examples of the application of the engineering approach to economic problems are Bain (1956), Gold (1974), and, of course, Tarr (1977).

The survivor technique, first used by Stigler (1958), essentially hypothesized that a plant of efficient size would survive in competition with other plants. Furthermore, if one plant size were more efficient than the others, its portion of the total market would increase. Thus, to find the MOS or efficient size, one can merely examine the distribution of plant sizes in an industry over time to see which ones have increased their market share or at least held their own. There are several problems with the technique. First using the technique by itself, one can not determine the exact nature and size of the advantage of the efficient plant. Second often the survivor technique only indicates a range of efficient plants, and often very odd size patterns emerge among the surviving plants; sometimes, for example, very small and very large plants are both gaining in market share. Third sometimes the exact criterion used to divide the plants or firms can change the results of the analysis. For instance, one researcher might use capacity as the size classification criterion, while another might use employment.[1] Besides Stigler, Saving (1961) and Weiss (1964) have used the survivor technique.

All three techniques have some advantages and some disadvantages. While the engineering technique indicates why a given plant is efficient, its estimate of the size of that plant is only hypothetical. In contrast, the survivor technique indicates which plant sizes hold their own in the market but not why. Therefore the survivor technique is a natural complement to the engineering technique, and it would be useful to examine the consistency of the two approaches.

III. Background on the Steel Industry and the Data

Steel is produced by three different types of plants: the predominant type in total production share being the conventional steel mill. This mill is a combination of three major components: the blast furnace which smelts the iron ore into iron or pig iron, the steel furnace which refines the iron into steel, and the rolling mill which rolls the steel into the shapes useful to the mill customers. The second most prevalent type of steel mill in production share is the Electric Furnace (EF) minimill which uses scrap steel. In many circumstances where scrap and electrical power are cheap and readily available, this is the lowest cost way of making steel. The third type of plant combines the Electric Furnace with the Direct Reduction of ore into iron without a blast furnace. Except in a few areas with very low gas prices, this technology is not cost effective. Consequently, the conventional mill consisting of the blast furnace, the steel furnace, and rolling mills is usually the low cost way to convert iron ore into useable steel products.[2]

Much happened in the steel industry during the period between Tarr's study and the year of our sample (1987). Between 1976 and 1987, total domestic shipments of steel dropped from 89 million to 76 million tons, and imports of steel rose from 14 million to 20.4 million tons. This has led to great changes in the industry. Many plants have closed, the number of conventional integrated mills with over a million tons (MT) a year capacity dropping from 44 to 23. In addition, several firms have entered into joint ventures with Japanese companies. These include California Steel (formerly Kaiser Steel), Rouge Steel

---

[1] For a further discussion of the three techniques, see Scherer and Ross (1990).

[2] For discussions of the Electric Furnace and Direct Reduction Iron, see Barnett and Crandall (1986), p. 73 and 86 and Guilherme de Heraclito Lima (1991), p. 7 and 43-44.

(formerly part of the Ford Motor Company), and the Great Lakes mill of National Intergroup.

Furthermore, there has been great technological change. Direct casting has changed the nature of the rolling mill process in both the conventional plant and the minimill. The minimills in general have expanded not only their total market share but also their product line. In 1990, one minimill company, Nucor, started to make sheet steel, which was heretofore a product only of the conventional mills. All these changes have led to substantial improvements in the productivity of the steel industry. Thus it is an interesting question as to whether Tarr's estimates of MOS would hold up during this period.

This paper focuses only on the conventional steel mill of over one million ton (1 MT). First sufficient data are not available to apply this technique to the minimill. Many of the minimill companies are privately held and do not make their capacity data public. Second, minimills cater to a wide variety of geographic and product markets, and an efficient size mill in one situation might not be efficient in another.[3] Thus there may be a quite wide range of efficient size minimills; Tarr finds that efficient minimills operate in a range of from 500,000 to 3 million ton per year (from 0.5 to 3 MT). Others have stated that even smaller minimills are competitive in many circumstances (Barnett and Crandall 1986). Given these problems, this paper will focus on conventional steel mills. The sample is further limited to conventional steel mills with a capacity of over 1 MT because conventional mills of smaller capacity usually manufacture specialty steels (e. g. stainless steel) that do not compete with the products of larger plants.

For integrated steel mills of over 1 MT, the usual steel furnace is a Basic Oxygen Converter (BOF), but sometimes other furnaces are used. A few mills still use an older technology, the Open Hearth (OH), and others use the Electric Furnace (EF) to refine the metal into steel. The latter type of furnace usually converts scrap into usable new steel; in forming and shaping the final steel product, the rolling mills of conventional steel plants generate a considerable amount of scrap.

---

[3] The same logic could be applied to conventional mills, but in general they tend to produce very similar, wide product mixes, which are sold in national markets. Therefore, their input and demand situations are quite homogenous, and applying the MOS criterion is appropriate.

IV. The Application of the Survivor Technique to the Integrated Steel Plant

Tarr's paper was the latest of a number of studies on economies of scale in the mid-twentieth century steel industry. (See Scherer (1975), Leckie and Morris (1968), and Pratten and Dean (1971).) Tarr focused on two types of steel mills: the conventional integrated mill and the electric furnace minimill. The Tarr estimates provide an ideal setting for comparing engineering estimates with those provided by the survivor technique. In particular, the most recent data on steel mills can be used to compare the actual sizes of present-day steel mills with Tarr's MOS estimates based on engineering approach in the mid-1970s.

With his engineering approach, Tarr concludes that the Minimum Optimal Scale (MOS) capacity for a conventional steel mill is 6 million tons (6 MT) of steel a year. Tarr's reason for this estimate is that the MOS for the modern blast furnace is roughly 3 MT a year, and a mill needs two such furnaces to maintain a continuous flow of product. Repair and maintenance requires that one furnace be out of production for considerable periods of time.

To conduct our survivorship test, capacity data were collected on conventional steel plants of over one million tons capacity (1 MT) for 1976. For 1987, however, yearly capacity data are readily available for only 12 of the 23 large conventional plants.[4] For these, either the yearly total plant capacity or the yearly capacity for each steel furnace within the plant is available. For the other 11 plants, the only available data are the number of furnaces and the heat sizes for each furnace.[5] Using this information and the information on the furnace configurations for the plants with yearly capacity available, we can estimate the capacity for these 11 plants.

To accomplish this task, the plants with yearly capacity data available are reexamined. In most of these plants, the heat sizes are available along with the yearly capacity data for the furnaces. From these data, we can compute a ratio between the yearly capacity and heat size for each of the three types of furnace (BOF, Open Hearth, and EF). This ratio describes the hypothetical number of heats that can be achieved in a year.

---

[4] The data sources are Institute for Iron and Steel Studies (1976) and Pietrucha and Deily (1977) for 1976 and Serjeantson, Cordero, Cooke, Sexton, and Jordain (1988) for 1987.

[5] No conventional mill of over 1 million tons capacity was missed. None have been built in the last thirty years, and none have expanded into this class from a smaller one.

For each furnace type, there is, however, a considerable range in these ratios. Thus, we compute the three different estimates of yearly capacity for each furnace in the plants without available yearly capacity. The first, the Medium estimate, is based on the average of the available heat size-yearly capacity ratios for the given type of furnace; the second, the Low Estimate, is computed from the average ratio minus one standard deviation for the sample; and the third, the High Estimate, is computed from the average ratio plus one sample standard deviation. From these estimates for the furnaces, we aggregate to arrive at three yearly capacity estimates for each plant.[6]

Based on these plants estimates, we obtain three 1987 plant size distributions; the Low Distribution assumes that each furnace without capacity data has a capacity equal to our Low Estimate. The Medium Distribution assumes that each furnace without capacity data has a capacity equal to our Medium Estimate, and High Distribution assumes that each furnace without capacity data has a capacity equal to our High Estimate. For the Low Distribution, the total capacity (of mills of over 1 MT) is 72.4 MT; for the Medium Distribution, it is 82.1 MT, and for the High Distribution, it is 92.1 MT.

Next, the plants are grouped into four size categories: over 7.5 MT, 4.5 to 7.49 MT, 1.5 to 4.49 MT, and 1.0 to 1.49 MT. While different sets of size categories could lead to different capacity class ratios between 1976 and 1987, there is a good rationale for using our categories. Suppose Tarr's estimate is correct. For an (all BOF) MOS plant which did not have capacity data, our estimation procedure would yield three capacity estimates: 4.62 MT (0.77 times 6), 6 MT, and 7.38 (1.23 time 6). Thus, given our estimating methodology, a Tarr hypothesized MOS plant would roughly encompass the 4.5 to 7.5 MT category.

Table I shows the plant size distributions for 1976 and 1987 given our three estimates of 1987 plant capacity. Assuming that the category, 4.5 to 7.5 MT, is a reasonable approximation of Tarr's MOS plant or range of plants, we examine the sample to see if the proportion of the total conventional plant capacity accounted for by this size class increased in the period, 1976 to 1987. As shown in the table, this category increased its market share according to all three distributions. The ratio of 1987 to

---

[6] When we apply the one standard deviation criterion to the BOF furnace, the Low estimate is 0.77 times the Medium estimate, and the High estimate is 1.23 times the Medium estimate. For the Electric Furnace, the Low estimate is 0.633 times the Medium estimate, and the High estimate is 1.368 times the Medium estimate. For the Open Hearth furnace, the Low estimate is 0.84 times the Medium estimate, and the High estimate is 1.55 times the Medium estimate.

1976 capacity share for this category is 1.46 for the Medium estimate, 1.37 for the Low estimate, and 2.21 for the High estimate. It is admittedly an increase in the share of a declining total since the total capacity in the United States of these over 1 MT plants dropped from 144.8 MT to 72.4, to 82.1 or to 92.1 MT depending on which 1987 distribution we accept.[7] The decline in total industry capacity lends an even more compelling significance to the increase in the market share by Tarr's MOS size category. In a market with falling demand, the pressure for technical efficiency is even greater than in markets with rising or stable sales.

Alternatively, the change in the shares of plants over the size classes may be due to random fluctuations with the underlying distribution of plants remaining unchanged. Thus, Chi-Square statistics were used to test for the hypothesis that the change in the shares was due to random variation. For all three distributions, the Chi Square test indicates that it is extremely unlikely that the change in plant distribution was due to chance, the Chi Square test being significant at the 99 per cent level for the High and Low distributions and significant at the 95 percent level for the Medium distribution. Therefore, we have strong evidence that the change in plant shares over our four size classes was caused by real variables operating in the environment and not merely by random fluctuations.

V. Conclusion

Our comparison of the size distribution of conventional steel plants for the years 1976 and 1987 indicates that the MOS plant size estimated by Tarr increased in relative importance among the plants of over 1 MT. Thus, the survivor technique gives estimates of sale economies for conventional steel mills that are consistent with Tarr's engineering approach methodology estimates. For this sample, then, the two of the methods for estimating scale economies or Minimum Optimal Size are consistent with each other. Combining Tarr's engineering estimates with our survivor analysis, we not only learn why plants of a given size are efficient but also whether the plants have passed the market test. Thus, this evidence gives one confidence in the engineering approach methodology. For all its problems, this method accurately predicted the size class which increased its market share in the eleven years period between 1976 and 1987.

---

[7] There are essentially three reasons for the decline in the capacity of the conventional plants: declining or constant total demand for steel, competition from foreign firms, and competition from scrap-fed Electric Furnace, a relatively new technology (See Barnett and Crandall 1986).

Table I
Distribution of U. S. Steel Mills of Over 1 MT* by Capacity, 1976 and 1987

I. Medium Estimate

Plant Size Category	**Percentage of Total Capacity** 1976**	1987**	**Ratio of 1987 to 1976**
Over 7.5 MT	16.4 (3)	9.5 (1)	0.58
4.5 to 7.49 MT	19.3 (5)	28.1 (4)	1.46
1.5 to 4.49 MT	61.4 (32)	60.7 (17)	0.99
1.0 to 1.49 MT	2.9 (4)	1.7 (1)	0.59
Total Capacity	144.8 MT (44)	82.1 MT (23)	

II. Low Estimate

Plant Size Category	**Percentage of Total Capacity** 1976**	1987**	**Ratio of 1987 to 1976**
Over 7.5 MT	16.4 (3)	0.0 (0)	0.00
4.5 to 7.49 MT	19.3 (5)	26.4 (3)	1.37
1.5 to 4.49 MT	61.4 (32)	69.9 (18)	1.14
1.0 to 1.49 MT	2.9 (4)	3.7 (2)	1.28
Total Capacity	144.8 MT (44)	72.4 MT (23)	

III. High Estimate

Plant Size Category	**Percentage of Total Capacity** 1976**	1987**	**Ratio of 1987 to 1976**
Over 7.5 MT	16.4 (3)	10.4 (1)	0.63
4.5 to 7.49 MT	19.3 (5)	42.6 (7)	2.21
1.5 to 4.49 MT	61.4 (32)	45.5 (14)	0.74
1.0 to 1.49 MT	2.9 (4)	1.5 (1)	0.52
Total Capacity	144.8 MT (44)	92.1 MT (23)	

* Equals millions of tons.
** The number of plants in each category are in parentheses.

References

Bain, J. **Barriers to New Competition**, Oxford: Blackwell, 1956.

Barnett, D. F. and R. W. Crandall, **Up From the Ashes: The Rise of the Steel Minimill in the United States**, Washington D. C.: The Brookings Institution, 1986.

Christensen, L. R. and W. H. Greene, "Economies of Scale in U. S. Electric Power Generation," Journal of Political Economy, LXXXIV, No. 4 (August 1976), p. 655-676.

Fisher, F. M., and J. J. McGowan, "On the Misuse of Accounting Rates of Return to Infer Monopoly Profits," American Economic Review, Vol. LXXIII (1983), p. 82-97.

Friedlaender, A. F., C. Winston, and K. Wang, "Costs, Technology, and Productivity in the U. S. Automobile Industry," Bell Journal of Economics, Vol. XIV, (Spring 1983), p. 1-20.

Friedman, M. "Comment on Caleb Smith," in **Business Concentration and Price Policy**, Princeton, N. J.: Princeton University Press 1955.

Gold, B. "Evaluating Scale Economies: The Case of Japanese Blast Furnaces," Journal of Industrial Economics, XXIII (Sept. 1974) p. 1-18.

Guilherme de Heraclito Lima, J., **Restructuring the U. S. Steel Industry**, Boulder CO.: Westview Press, 1991.

Institute for Iron and Steel Studies, "1976 - The Road Back," Commentary, V, No. 1, 2 (January-February 1976).

Leckie, A. H. and A. J. Morris, "Effect of Plant and Works Scale on Costs in the Iron and Steel Industry," Journal of the Iron and Steel Institute, May 1968, p. 442-52.

Moody's, **Moody's Industrials**, 1980-1988.

Pietrucha, W. E. and R. L. Deily, **Steel Industry in Brief: Databook, U.S.A. 1977**, Green Brook, N. J.: Institute for Iron and Steel Studies 1977.

Pratten, C. and R. M. Dean with A. Silberston, **The Economies of Large Scale Production in British Industry**, Cambridge: Cambridge University Press, 1965.

Savings, T. R. "Estimation of the Optimal Size of Plant by the Survivor Technique", Quarterly Journal of Economics, LXXV, Nov. 1964, p. 569-607.

Scherer, F. M. and D. Ross, **Industrial Structure and Economic Performance**, Boston: Houghton Mifflin Company, 1990.

Scherer, F. M., "The Technological Basis of Plant Economies in Twelve Manufacturing Industries," **Mimeo** 1975.

Serjeantson, R., R. Cordero, H. Cooke, S. Sexton, and S. Jordain, **Iron and Steel Works of the World**, 1988 9th Edition, Surrey, England, Metal Bulletin Books, Ltd. 1988.

Stigler, G. "The Economies of Scale," **Journal of Law and Economics**, I, Oct. 1958, p.54-71.

Tarr, D. G. "The Minimum Optimal Scale Steel Plant in the Mid -1970's," FTC Working Paper, No. 3, March 1977.

Tarr, D. G. "The Minimum Optimal Scale Steel Plant," **Atlantic Economic Journal**, XII, No. 2, (1984), p. 122.

Weiss, L. R. "The Survival Technique and the Extent of Suboptimal Capacity," Journal of Political Economy, LXXII, No. 3 (June 1964), p. 246-261.