Modelling Price Fluctuations of Iron and Steel Scrap and Scrap-Based Light Non-Flat Steel Products

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The World Bank

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MODELLING PRICE FLUCTUATIONS OF IRON AND STEEL SCRAP
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SUMMARY AND CONCLUSIONS

Light non-flat steel products (concrete reinforcing bars, merchant bars, light sections and wire rods) have unique characteristics, which are distinct from other steel products. Among these characteristics, first, light non-flat steel products are consumed largely by the construction and civil engineering industry, which are highly sensitive to business cycles. Second, they are produced mainly from iron and steel scrap. Because one half of scrap used by the iron and steel industry is produced as a by-product of steel-making and because scrap consumption is mostly dependent upon technological coefficients relating to steel-making furnace-types, its supply and demand are both price-inelastic. As a result, prices of light non-flat steel products and scrap fluctuate wildly and simultaneously.

This paper presents a model that solves the interrelationships between both markets. The model is developed as a linear complementarity programming (LCP) problem, which has been applied to a few other minerals and metals industries. LCP is most useful in capturing markets of scrap and light non-flat products, where price-inelasticities are characteristics on both supply and demand sides. This is because LCP can solve a quantitative relationship between a given constraint and its impact on other variables.

Although the equations and parameters used in this paper are preliminary ones, the model seems to be robust in analyzing unstable and simultaneous price movements of scrap and light non-flat products, as exemplified in the model experiments that were designed to reproduce the tight market situation in 1974. The model may be applied to other metal and scrap markets without substantial changes. Furthermore, the present model is a static one, which aims primarily at analyzing short-run price projections; however, it provides a theoretical framework to project long-run trends as well.
I. Introduction

Light non-flat steel products, which consist of concrete reinforcing bars (rebars, in short), merchant bars, light sections 1/ and wire rods, are largely produced from iron and steel scrap by small-scale non-integrated steel mills. They are mostly consumed by the construction and civil engineering industry. Prices of light non-flat products and scrap fluctuate wildly and often move together. This paper presents a model that analyzes the inter-relationships between markets of iron and steel scrap (scrap, in short) and those of light non-flat products that are produced by small-scale scrap-based mills (SB-LNFP, in short).

Unstable prices of scrap and SB-LNFP can be attributed to three different but related factors. First, the instability of scrap prices is rooted in the very nature of scrap—inelastic supply and demand with respect to price. On the supply side, because a large portion of scrap used in the iron and steel industry is generated as a by-product of iron and steel production, its supply is determined by the level of steel production, not by scrap prices. Supply of scrap from various sources outside the iron and steel industry (so-called purchased scrap) is also considered to be price-inelastic, particularly when the supply approaches a certain limit. On the demand side, demand for scrap in production of SB-LNFP is a derived demand for steel products; thus, its demand is also price-inelastic. Because of these price inelasticities, a slight change in supply of and/or demand for scrap results in a considerable impact on its prices.

1/ The definitions of merchant bars and light sections have not been firmly established. Light sections in this paper are referred to as angles and channels. However, some of them, particularly those of small sizes, are often called merchant bars.
Second, most of SB-LNFP is used by the construction and civil engineering industry, the activity level of which is sensitive to business cycles; as a result, demand for those products fluctuates widely along with business cycles. Third, unlike other steel products, SB-LNFP is produced mostly by a large number of small-scale scrap-based producers—large-scale integrated iron and steel mills (integrated mills, in short) do not produce much of those products in many countries. For SB-LNFP producers, market arrangements to stabilize prices are the least likely thing. Fourth, large-scale integrated mills also consume a significant amount of scrap. Because of the largeness of those mills, a slight change in their steel production and the scrap usage pattern affects scrap balances, particularly scrap availability to SB-LNFP mills, which must rely on outside scrap.

Simultaneous movements of both scrap and SB-LNFP prices are the result of the following interrelationships existing between both markets: (1) SB-LNFP is produced from scrap, which constitutes a large portion of SB-LNFP production costs (about 45%) \(^1\) and (2) SB-LNFP mills are the major buyers of scrap. (SB-LNFP mills consume about 40% of purchased scrap.) The instability embedded in each market stated above is, thus, multiplicated by these interrelationships.

This paper presents a model that solves scrap and SB-LNFP markets endogenously. The scrap balance of large-scale integrated mills and other scrap users is treated exogenously but explicitly. The model is developed as a linear complementarity programming (LCP) problem. \(^2\) The LCP modelling

technique has been applied to various minerals and metals markets. 1/ A general form of LCP is given in Appendix 2.

LCP is most useful in capturing scrap and SB-LNFP markets, where price-inelasticities are characteristics on both supply and demand sides. This is because LCP can solve a quantitative relation between a given constraint (for example, an upper limit on supply capability of scrap) and its impact on other variables (for example, scrap price). The methodology developed in this model can be applied to other metal and scrap markets.

II. Overview of Scrap and SB-LNFP Markets

This section provides an overview of scrap and SB-LNFP markets, by presenting an "average" picture of those markets in the US, EC and Japan (in the major regions, hereinafter) between 1972 and 1979. The numerical figures used in this section are referred to as annual averages of the major regions of this period, unless otherwise stated. The reason why the "average" picture covers only the major region is simply because of the lack of statistical data in other regions; not because of a limited importance of those regions in SB-LNFP production. On the contrary, it is broadly known that developing countries have a comparative advantage in SB-LNFP production vis-a-vis other steel products. Their share in SB-LNFP production among the market economies is much higher than in total steel production. 1/

Figure 1 schematically illustrates the relationships among scrap, SB-LNFP and steel with the annual average figures in the period between 1972 and 1979 in the US, EC and Japan combined.

A. Iron and Steel Industry and Iron Foundries

With respect to scale of mills, iron and steel-making processes and their products, the iron and steel industry may well be classified into three distinct types of mills:

1/ Of the 118 million tons of light non-flat products produced in the market economies in 1979, the developing countries accounted for 25%. This 25% share is much higher than the developing countries' 15% share in the market economies' production of all steel, indicating a relatively wide diffusion of light non-flat production in the developing countries. Within the developing countries, Brazil, India, Spain and the Republic of Korea are the major producers of light non-flat products.
(1) large-scale integrated mills;
(2) small-scale SB-LNFP mills; 1/ and
(3) scrap-based special steel mills.

Furthermore, because of their importance in scrap markets, we may add:

(4) iron foundries

to our consideration, although they are not generally considered as a part of
the iron and steel industry. Among total steel production, the percentage
share of large-scale integrated mills is estimated at about 84%, small-scale
SB-LNFP mills 12%, and scrap-based special steel mills 4% (Table 2.1). 2/

1/ A new type of integrated iron and steel mill--based on iron production by
direct reduction and steel production by electric arc furnaces--is gaining
popularity, particularly among developing countries because the required
scale of production capacity is much smaller than in the traditional
blast-furnace process. (At the end of 1979, the direct reduction capacity
was estimated at about 2.5% of world pig iron production in the same
year.) Although they produce iron and steel in an integrated manner, they
have more similarity with small-scale SB-LNFP mills than with large-scale
integrated mills, in view of plant-size, steel-making process (mainly,
electric arc furnaces) and products (mainly, light non-flat products).
Thus, in this paper, integrated mills of this type are classified as a
part of small-scale SB-LNFP mills.

2/ This estimation is made on the basis of the following assumptions:

(1) 60% of small bars and light sections is produced by small-scale scrap-
    based mills; the balance is by large-scale integrated mills;
(2) 25% of wire rods is produced by small-scale scrap-based mills; the
    balance is by large-scale integrated mills; and
(3) 30% of special steel is produced by small-scale scrap-based special
    steel mills; the balance is by large-scale integrated mills; and
(4) all other steel products are made by large-scale integrated mills.
<table>
<thead>
<tr>
<th></th>
<th>Basic oxygen furnace</th>
<th>Open hearth furnace</th>
<th>Electric arc furnace</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large-scale integrated mills</td>
<td>246.2</td>
<td>49.2</td>
<td>12.2</td>
<td>307.6</td>
</tr>
<tr>
<td>SB-LNFP mills</td>
<td>.0</td>
<td>.0</td>
<td>45.5</td>
<td>45.5</td>
</tr>
<tr>
<td>Scrap-based special steel mills</td>
<td>.0</td>
<td>.0</td>
<td>14.0</td>
<td>14.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>246.2</strong></td>
<td><strong>49.2</strong></td>
<td><strong>71.7</strong></td>
<td><strong>367.1</strong></td>
</tr>
</tbody>
</table>

\* An annual average between 1972 and 1979.

Source: The author's estimates based on statistics of crude steel production by furnace type and the assumptions stated below.

Large-scale integrated producers are the primal part of the iron and steel industry. Their scale of production is indeed large, ranging from one million tons per year well up to 30 million tons per year. Furthermore, steel production is concentrated in ultra-large-scale steel companies. The largest ten steel companies in the market economies account for one-third of their total crude steel production. In integrated mills, steel is produced in two steps. Iron ore is converted into pig iron at blast furnaces; then, pig iron is reduced into steel, typically at basic oxygen furnaces (see Table 2.1). Although large-scale integrated mills produce a variety of steel products, including light non-flat products and special steel, their clear advantage over the other two mill types lies in production of flat products such as sheets and plates. Most of the large-scale integrated mills in the US and Japan stopped production of light non-flat products in the late 1960s or early 1970s. Mills in the EC are following this trend.
As reviewed later in detail, SB-LNFP producers make a sharp contrast with large-scale integrated mills in many aspects. They produce steel from purchased scrap by using electric arc furnaces. Their products are primarily light non-flat products of low quality, represented most typically by rebars. The production scale is small. Although a few companies produce two million tons of steel per year, most of SB-LNFP producers produce 100,000 tons to 500,000 tons per year. Smaller mills, known as mini-mills, produce only 10,000 tons to 100,000 tons. Despite their small scale, some SB-LNFP producers are making a strong showing, in a sharp contrast with financially troubled large-scale integrated mills. This is one of the reasons why keen attention has been paid to SB-LNFP producers in recent years.

Scrap-based special steel mills have a strong similarity to SB-LNFP mills. Their scale of production is relatively small. They use scrap in steel-making; thus, they compete with SB-LNFP producers in scrap markets. Special steel, which is used in a variety of industries, is one of a few steel products, demand for which is increasing at the present time in the midst of the depressed steel markets. In this paper, however, scrap-based special steel mills are not touched upon, except when their demand for scrap affects the total scrap balance.

B. Scrap Markets

1. Supply

Scrap used by the iron and steel industry and iron foundries is supplied from two different sources: within and outside iron and steel mills. Scrap generated within these mills is called home scrap, while scrap generated
outside is called purchased scrap. 1/ In the major regions, the iron and steel industry and iron foundries generated about 100 million tons of scrap annually on the average between 1972 and 1979 (Table 2.2).

Table 2.2: TOTAL GENERATION, CONSUMPTION AND BALANCE OF SCRAP BY TYPE OF MILL /a
(million tons per year)

<table>
<thead>
<tr>
<th>Type of Mill</th>
<th>Scrap generation</th>
<th>Scrap consumption</th>
<th>Scrap balance /b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large-scale Integrated mills</td>
<td>73.4</td>
<td>100.7</td>
<td>-27.3</td>
</tr>
<tr>
<td>SB-LNFP mills</td>
<td>10.9</td>
<td>46.1</td>
<td>-35.2</td>
</tr>
<tr>
<td>Scrap-based special steel mills</td>
<td>3.4</td>
<td>14.5</td>
<td>-11.1</td>
</tr>
<tr>
<td>Iron foundries</td>
<td>12.8</td>
<td>31.0</td>
<td>-18.2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100.5</strong></td>
<td><strong>192.3</strong></td>
<td><strong>-91.8</strong></td>
</tr>
</tbody>
</table>

/a An annual average between 1972 and 1979.

/b The figures of scrap generation were derived from the statistics shown in Japan Iron and Steel Federation, Tekko Tokei Yoran, while those of scrap consumption were derived from the unit scrap consumption (shown in ibid.) times crude steel production. The resulted scrap balance is about 15 million tons lower than the statistics of purchased scrap shown in ibid.

Source: The author's estimates, based on Tables 2.1 and 2.5 and ibid.

The average supply of purchased scrap is estimated at about 90 million tons per annum. Home scrap accounts for 52% of total scrap supply and purchased scrap for 48%.

1/ Purchased scrap is defined as all scrap, regardless of sources, that is subject to commercial transactions. While some home scrap finds its way to the scrap trade, most home scrap remains within its home plant. Thus, purchased scrap is comprised mainly of prompt industrial and obsolete scrap. In the US, obsolete scrap accounts for 60%-65% of total purchased scrap. (W. Hogan and F. Koelble, Purchased Ferrous Scrap, the United States Demand and Supply Outlook, 1977, pp.6 and 121.)
In the iron and steel industry, home scrap is generated as a by-product of iron and steel production; as a result, its supply is determined by (1) the level of crude steel production, and (2) yield (the tonnage of finished steel products produced from one ton of crude steel). Consequently, supply of home scrap is totally price-inelastic. In the major regions, between 1972 and 1979, an average of 240 kg of scrap was generated from the whole production process (from iron-making through rolling process) which produced one ton of steel products (in crude steel equivalent) (Table 2.3). Because of the improvement in yield, resulting particularly from the expansion of continuous casting, \(1/\) scrap generation per ton of steel was reduced significantly in the 1970s from 248 kg in 1972 to 222 kg in 1979 (Table 2.4). As more steel is continuously cast in the future, scrap generation per ton of steel production will further decrease.

Purchased scrap is further classified into prompt industrial and obsolete scrap. Prompt industrial scrap is generated by iron and steel consuming industries in the course of manufacturing. Its generation is thus related to industrial activity, being insensitive to changes in prices. \(2/\)

Because of technological improvements in the industry as a whole, the tonnage of scrap generated at a given level of industrial activity is declining.

---

1/ Continuous casting is a relatively new method which allows many traditional steps to be bypassed; ingot teeming, stripping, soaking and rolling are not required.

Table 2.3. UNIT GENERATION, CONSUMPTION AND BALANCE OF SCRAP BY FURNACE TYPE (kg per ton of crude steel production)

<table>
<thead>
<tr>
<th>Scrap generation</th>
<th>Scrap consumption</th>
<th>Scrap balance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic oxygen furnaces</td>
<td>239</td>
<td>231</td>
</tr>
<tr>
<td>Open hearth furnaces</td>
<td>239</td>
<td>614</td>
</tr>
<tr>
<td>Electric arc furnaces</td>
<td>239</td>
<td>1,030</td>
</tr>
<tr>
<td>All furnaces</td>
<td>239</td>
<td>427</td>
</tr>
</tbody>
</table>

Source: The present author's estimates, based on the statistics of total scrap generation and scrap consumption by furnace type shown in Japan Iron and Steel Federation, op. cit. (various issues).

Table 2.4: TRENDS IN SCRAP GENERATION AND CONTINUOUS CASTING

<table>
<thead>
<tr>
<th>Scrap generation per ton of steel production</th>
<th>Percentage of continuously cast steel to total steel production</th>
</tr>
</thead>
<tbody>
<tr>
<td>(kg)</td>
<td>(%)</td>
</tr>
<tr>
<td>1972</td>
<td>248</td>
</tr>
<tr>
<td>1973</td>
<td>247</td>
</tr>
<tr>
<td>1974</td>
<td>242</td>
</tr>
<tr>
<td>1975</td>
<td>247</td>
</tr>
<tr>
<td>1976</td>
<td>240</td>
</tr>
<tr>
<td>1977</td>
<td>240</td>
</tr>
<tr>
<td>1978</td>
<td>228</td>
</tr>
<tr>
<td>1979</td>
<td>222</td>
</tr>
</tbody>
</table>

Source: The source for scrap generation is identical to the source in Table 2.2. As for percentage of continuously cast steel, Japan Iron and Steel Federation, op. cit.
Obsolete scrap, which is obtained in discarded products and collected from many miscellaneous sources, constitutes the most nebulous part in the scrap supply. Because of the extreme diversity of items that contain iron and steel, the heterogeneity in its physical and chemical characteristics, and the wide geographical dispersion, its recycling as purchased scrap requires extensive efforts in sorting, processing and distribution on the part of the ferrous scrap industry which consists of scrap processors and brokers. Therefore, unlike home and prompt industrial scrap, there is more room for scrap prices to adjust supply to changing demand (including speculative demands). As for the degree of price sensitivity of obsolete scrap supply, however, two studies relating to the period 1973-74 in the US came to very different conclusions. Although the present author is not ready to take either one definitely, it is generally considered that the supply is sensitive to price changes up to a certain level of quantity but that it becomes quickly price-inelastic beyond that level.

2. Demand

Scrap is used by the iron and steel industry and iron foundries. In the major regions, these industries altogether consumed about 190 million tons of scrap annually on the average between 1972 and 1979 (Table 2.2). The iron and steel industry consumed about 160 million tons or 84% of total scrap consumption, while iron foundries consumed about 30 million tons.

---

1/ Hogan and Koelble found an almost perfectly inelastic supply, suggesting a price elasticity of 0.07. (W. Hogan and F. Koelble, op. cit., 1977, p. 130.) The study undertaken by Robert R. Nathan Associates, Inc. commissioned by the Metal Scrap Research and Education Foundation (a research arm of the Institute of Scrap Iron and Steel) derived a higher-than-unity elasticity. (Robert R. Nathan Associates, Inc., op. cit.)
In the iron and steel industry, scrap is consumed mostly for steel-making. (Only a small amount is used for iron-making.) Thus, demand for scrap is determined basically by three factors:

(1) the level of production of crude steel;

(2) the distribution of steel production according to type of furnace, and;

(3) relative prices of scrap vis-a-vis other charge metallics.

The first is self-evident, but the second and third may deserve some explanations.

Currently, steel is made by three major furnace types: basic oxygen, open hearth and electric arc furnaces. For technological reasons the use of scrap in steel-making differs widely among these three furnace types. For example, basic oxygen furnaces, which utilize the heat of hot metal (i.e., molten pig iron) as the basic energy source, have a physical upper limit of scrap uses, probably 400 kg per ton of crude steel production. Electric arc furnaces can charge only scrap and/or directly reduced iron. \(^1\) Open hearth furnaces have the most flexibility among these three furnace types; the scrap ratio can vary from 100 kg to 700 kg per ton of crude steel production. Because large-scale integrated mills largely rely on basic oxygen furnaces (Table 2.1), they consume only 231 kg of scrap to produce one ton of crude steel (Table 2.3). SB-LNFP and scrap-based special steel mills, which are almost totally dependent upon electric arc furnaces, consume as much as 1,030 kg of scrap to produce a ton of crude steel.

\(^1\) The importance of directly reduced iron as charge metallics for steel-making has been increasing in recent years; however, its percentage share to total charge metallics is still low (2.5% in 1979). Thus directly reduced iron is omitted in the calculation of use of charge metallics.
As for relative prices of scrap vis-a-vis other charge metallics, particular attention must be paid to scrap uses in basic oxygen furnaces. Although the flexibility of scrap uses in basic oxygen furnaces is limited, there still exists some flexibility, with the scrap ratio ranging from about 10% to 30%. This means that large-scale integrated mills can change the ratio between scrap and other charge metallics in their basic oxygen furnace operations, to some extent. Scrap use will decline as scrap prices approach the level of production costs of hot metal. Because of the high percentage of steel produced by basic oxygen furnaces to total steel production (see Table 2.1), a slight change in the scrap ratio in basic oxygen furnaces of large-scale integrated mills affects total scrap consumption of the whole steel industry significantly.

3. Balance

Between 1972 and 1979, the iron and steel industry and iron foundries in the major regions as a whole generated 101 million tons of scrap and consumed 192 million tons annually (Table 2.5). This left a deficit of 92 million tons or 48% of their total scrap consumption and the deficit was filled by purchased scrap. Large-scale integrated mills, which mostly relied on basic oxygen furnaces, had a deficit of 27 million tons or 27% of their total scrap consumption. SB-NNFP and scrap-based special steel mills together had a deficit of 46 million tons or as much as 76% of their total scrap consumption. Iron foundries had a deficit of 18 million tons or 59% of their total scrap consumption.
Table 2.5: DEMAND FOR SB-LNFP AND PURCHASED SCRAP (thousand tons)

<table>
<thead>
<tr>
<th></th>
<th>SB-LNFP</th>
<th>Purchased Scrap</th>
</tr>
</thead>
<tbody>
<tr>
<td>1972</td>
<td>40,921</td>
<td>83,615</td>
</tr>
<tr>
<td>1973</td>
<td>45,496</td>
<td>93,068</td>
</tr>
<tr>
<td>1974</td>
<td>47,680</td>
<td>96,227</td>
</tr>
<tr>
<td>1975</td>
<td>36,775</td>
<td>71,050</td>
</tr>
<tr>
<td>1976</td>
<td>40,461</td>
<td>76,189</td>
</tr>
<tr>
<td>1977</td>
<td>39,995</td>
<td>85,918</td>
</tr>
<tr>
<td>1978</td>
<td>42,040</td>
<td>92,420</td>
</tr>
<tr>
<td>1979</td>
<td>45,992</td>
<td>99,219</td>
</tr>
<tr>
<td>Annual average</td>
<td>42,420</td>
<td>87,100</td>
</tr>
</tbody>
</table>

a/ Because of different data sources, there is a slight discrepancy between this figure and the one in Table 2.2.

Source: United Nations, Economic Commission for Europe, op. cit. for SB-LNFP (also see the assumption stated in Appendix) and Japan Iron and Steel Federation, op. cit. for purchased scrap.

Of the total average annual supply of purchased scrap, SB-LNFP mills accounted for 38%, large-scale integrated mills for 30%, scrap-based special steel mills for 12%, and iron foundries for 20%. (Table 2.2) In view of the relatively low share (12%) of SB-LNFP mills in total steel production, the importance of SB-LNFP mills in markets for purchased scrap is outstanding.

C. SB-LNFP Markets

Light non-flat products are divided into two groups: (1) small bars and light sections and, (2) wire rods. Small bars and light sections (less than 80 mm in diameter) are further classified into rebars, merchant bars and light sections. The major user of these products is the construction and civil engineering industry, while some merchant bars are used by the automotive and machinery industries. Wire rods are also classified into two types. The first
type consists of low-quality wire rods that are used for wire, nails and other miscellaneous materials. The second type is made up of high-quality wire rods that are used as industrial fasteners. Small bars and light sections and wire rods have two common features: (1) most of them are produced by small-scale scrap-based mills and (2) they are used largely by the construction and civil engineering industry.

Between 1972 and 1979, the annual production of total light non-flat products in the major regions amounted to about 76 million tons or about 26% of total steel production. 1/ The average annual production of small bars and light sections was 54 million tons and that of wire rods was 22 million tons. In the same period, the major regions' net exports of light non-flat products amounted to 7.4 million tons annually. The average annual apparent consumption was 69 million tons. Although there are no clear statistics, the percentage share of light non-flat production by small-scale scrap-based mills to total light non-flat production was estimated at about 50%. 2/ The balance went to large-scale integrated mills. The share of scrap-based mills is higher in production of small bars and light sections than in production of wire rods, because the latter has a higher percentage of high-quality products.

The reason why small-scale scrap-based mills play an important role in light non-flat production cannot be separated from the instability of its markets. In view of frequent and rapid changes in its demand, small-scale scrap-based mills have an advantage over large-scale integrated mills in


2/ Based on the assumptions stated in p.6.
Table 2.6: PRICES *a/* OF REBARS AND SCRAP
(1980 constant $/ton)

<table>
<thead>
<tr>
<th>Year</th>
<th>Rebars b/</th>
<th>Scrap c/</th>
</tr>
</thead>
<tbody>
<tr>
<td>1972</td>
<td>237</td>
<td>80</td>
</tr>
<tr>
<td>1973</td>
<td>399</td>
<td>112</td>
</tr>
<tr>
<td>1974</td>
<td>522</td>
<td>186</td>
</tr>
<tr>
<td>1975</td>
<td>318</td>
<td>108</td>
</tr>
<tr>
<td>1976</td>
<td>333</td>
<td>112</td>
</tr>
<tr>
<td>1977</td>
<td>266</td>
<td>87</td>
</tr>
<tr>
<td>1978</td>
<td>300</td>
<td>94</td>
</tr>
<tr>
<td>1979</td>
<td>363</td>
<td>111</td>
</tr>
<tr>
<td>Average</td>
<td>342</td>
<td>111</td>
</tr>
</tbody>
</table>

*a/* Deflated by the US Wholesale Price Index (1980=100).

b/ Antwerp price.

c/ Composite scrap price at Pittsburgh, Philadelphia and Chicago.

Source: *Metal Bulletin*, (various issues).
III. A Model of Scrap and SB-LNFP Markets

A. Outline of the Model

This section presents a model of scrap and SB-LNFP markets. The model is developed as an LCP problem and solves a static picture of those markets, focusing on the interrelationships between those two markets.

The major assumptions used in this model are in the following:

1. A demand function for SB-LNFP and a supply function of purchased scrap are econometrically estimated on respective prices and other exogeneous variables, and demand for scrap by SB-LNFP mills is linked to SB-LNFP production through an appropriate input-output coefficient;

2. Net demand for purchased scrap by other steel producers (i.e., large-scale integrated and scrap-based special steel mills) is treated exogenously and it is assumed that those mills substitute other charge metallics (pig iron or directly-reduced iron) for scrap when the scrap price reaches the production costs of other charge metallics;

3. There are upper limits of both SB-LNFP production capacities and supply capability of purchased scrap; and

4. There is no stock change in either SB-LNFP or scrap.
B. Notation

Quantity variables are referred to as annual figures.

1. Endogenous variables

DFL = Demand for SB-LNFP (million tons in finished products).

DCL = Demand for SB-LNFP (million tons in crude steel equivalent).

LL = Activity level of SB-LNFP (million tons in crude steel equivalent).

GS = Generation of scrap by SB-LNFP mills (million tons).

DS = Demand for scrap by SB-LNFP mills (million tons).

AP = Availability of purchased scrap to SB-LNFP mills (million tons).

SP = Supply of purchased scrap (million tons).

TP = Transactions of purchased scrap from suppliers to consumers (million tons).

RS = Reduction of scrap uses by substitution at large-scale integrated mills (million tons).

PFL = Price of SB-LNFP ($ per ton in finished products).

PC' = Price of SB-LNFP ($ per ton in crude steel equivalent).

PKL = A windfall profit ($ per ton in crude steel equivalent) accruing to SB-LNFP producers, resulting from the capacity limit of SB-LNFP production.

PVS = Value of scrap ($ per ton) generated and recycled in SB-LNFP mills.

PDS = Demand price of scrap in scrap markets for SB-LNFP producers ($ per ton).

PSS = Supply price of scrap in scrap markets for SB-LNFP producers ($ per ton).

PDP = Demand price of purchased scrap ($ per ton).

PSP = Supply price of purchased scrap ($ per ton).

PKP = A windfall profit ($ per ton in scrap) accruing to suppliers of purchased scrap, resulting from the supply capacity limit of purchased scrap.
2. Slack Variables

To indicate slack variables, letter W is attached to the corresponding variables.

3. Exogenous Variables

\[ \text{COC} \] = Normal mark-up, capital and operating costs other than scrap costs ($ per ton in crude steel equivalent).

\[ \text{PUS} \] = Upper limit of scrap price ($ per ton) that triggers substitution of other charge metallics for scrap by large-scale integrated mills.

\[ \text{DIP} \] = Demand for purchased scrap by large-scale integrated and other mills (million tons).

\[ \text{CUL} \] = Upper limit of SB-LNFP production capacity (million tpy in crude steel equivalent).

\[ \text{CUP} \] = Upper limit of supply capability of purchased scrap (million tons).

4. Parameters

\[ \phi \] = Conversion factor of steel products in terms of crude steel equivalent to those in terms of finished products.

\[ \rho \] = Amount of scrap (ton) that is generated from production of one ton of crude steel.

\[ \mu \] = Amount of scrap (ton) that is consumed to produce one ton of crude steel.

\[ \gamma \] = Upper limit of capacity utilization rate of SB-LNFP production.

\[ \omega \] = Price coefficient in the inverse demand function for SB-LNFP.

\[ \lambda \] = Intercept of the inverse demand function for SB-LNFP.

\[ \eta \] = Price coefficient in the inverse supply function of purchased scrap.

\[ \nu \] = Intercept in the inverse supply function of purchased scrap.
C. Market Equilibrium Conditions

All the equilibrium conditions are shown in a tableau form (Figure 2). Some conditions are explained below.

1. Equilibrium Conditions Regulating Price and Quantity Variables

There are two equilibrium conditions of this kind: demand function for SB-LNFP and supply function of purchased scrap. An equilibrium condition that regulates demand for SB-LNFP and its price is shown in the following pair of equations:

\[
WD_{FL} = \omega D_{FL} + P_{FL} - \lambda > 0 \quad \text{and} \quad WD_{FL}D_{FL} = 0 \quad (1)
\]

The pair of the equations means that demand quantity and price must satisfy the given demand function with equality, as long as demand quantity is strictly positive.

By the same token, the condition that regulates supply of purchased scrap and its price is shown in the following:

\[
WS_{P} = \eta S\bar{P} - P_{SP} + \nu > 0 \quad \text{and} \quad WS_{P}S_{P} = 0 \quad (2)
\]

2. Equilibrium Conditions among Quantity Variables

Demand for SB-LNFP

The following pair of equations converts demand quantity of SB-LNFP expressed in terms of finished products into the quantity expressed in terms of crude steel equivalent through a given conversion factor:

\[
WP_{FL} = -D_{FL} + ^{\phi} D_{CL} > 0 \quad \text{and} \quad WP_{FL}P_{FL} = 0 \quad (3)
\]
FIGURE 2: TABLEAU FOR THE MODEL OF SCRAP AND SB–LNFP MARKETS

<table>
<thead>
<tr>
<th></th>
<th>DEL</th>
<th>DCL</th>
<th>LL</th>
<th>GS</th>
<th>DS</th>
<th>AP</th>
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Demand for SB-LNFP is limited by the activity level of its production:

\[ WPCL = -DCL + LL > 0 \quad \text{and} \quad WPCL.PCL = 0 \] (4)

The activity level is further bound by the existing production capacity. The pair of the following equations means that (1) the activity level of SB-LNFP cannot exceed the existing production capacity (adjusted by an appropriate capacity utilization rate) and (2) if the activity level reaches the production capacity constraint, a windfall profit (or an economic rent) accrues to SB-LNFP suppliers.

\[ WPKL = -LL + yCUL > 0 \quad \text{and} \quad WPKL.PKL = 0 \] (5)

**Activity Level, and Scrap Generation and Consumption at SB-LNFP Mills**

From their steel-making, SB-LNFP mills generate home scrap. The relation between their activity level and scrap generation is shown below:

\[ WPVS = p LL - GS > 0 \quad \text{and} \quad WPVS.PVS = 0 \] (6)

On the other hand, to produce their products, SB-LNFP mills require a certain amount of scrap. Their scrap requirement is derived from the activity level of SB-LNFP production and a given input-output coefficient:

\[ WPDS = -\mu LL + DS > 0 \quad \text{and} \quad WPDS.PDS = 0 \] (7)

**Markets of Purchased Scrap**

For convenience of explanation, let us assume that there are two distinct markets of scrap. The first market encompasses distribution of
purchased scrap among its suppliers, large-scale integrated mills and SB-LNFP producers, while the second scrap market deals distribution of scrap within the SB-LNFP sector.

In the first scrap market, again for convenience of explanation, let us assume that all purchased scrap is collected and redistributed by intermediaries i.e., scrap dealers.

\[ WPSP = SP - TP > 0 \quad \text{and} \quad WPSP \cdot PSP = 0 \]  

In the equation stated above, TP stands for quantities of purchased scrap dealt with by scrap dealers. The quantity of purchased scrap transactions cannot exceed its supply quantity.

As noticed often, scrap dealers face difficulties in their procurements of purchased scrap, when the quantity reaches a certain level. Thus, an upper limit of supply capability of purchased scrap is introduced into the model:

\[ WPKP = -TP + CUP > 0 \quad \text{and} \quad WPKP \cdot PKP = 0 \]  

The pair of these equations means that (1) transactions of purchased scrap cannot exceed a certain level and (2) a windfall profit accrues to suppliers of purchased scrap when the quantity transacted reaches a given upper limit.

\[ WPDP = -AP + TP - (DIP - RS) > 0 \quad \text{and} \quad WPDP \cdot PDP = 0 \]  

In the equations stated above, RS stands for a quantity of purchased scrap that large-scale integrated mills forgo by substituting other charge metallics for scrap, when scrap price reaches a certain level (i.e., production costs of pig iron or directly-reduced iron). \( DIP \) stands for a quantity of purchased
scrap that large-scale integrated mills require, before the substitution induced by scrap prices take place. (In this model, DIP is assumed to be determined outside the model.) Thus, (DIP-RS) stands for net requirements of purchased scrap by large-scale integrated mills. The pair of the equations means that (1) the sum of the availability of purchased scrap to SB-LNFP mills plus the net requirement of it by large-scale integrated mills cannot exceed all transactions of purchased scrap and (2) price of purchased scrap is zero, if there is a surplus in purchased scrap.

In the second scrap market, the following pair of equations regulates the relationship between scrap requirement and its availability to SB-LNFP mills:

\[
W_{PSS} = GS - DS + AP > 0 \quad \text{and} \quad W_{PSS}.PSS = 0
\]

(11)

This means that (1) total demand for scrap by SB-LNFP producers cannot exceed the sum of the total scrap availability to those producers (i.e., the sum of home and purchased scrap) and (2) the price of scrap is zero if the total availability exceeds requirements.

3. Equilibrium Conditions among Price Variables

Demand and Supply Prices of Scrap

Demand price of purchased scrap is given by the following equations:

\[
W_{TP} = - PDP + PSP + FK_P > 0 \quad \text{and} \quad W_{TP}.TP = 0
\]

(12)

In the first equation, the first term represents demand price of purchased scrap, and the second term means supply price, or the point on the supply function that corresponds to the equilibrium supply quantity. The last term
stands for a windfall profit accruing to suppliers of purchased scrap, which is solved as the Lagrangean multiplier of a given constraint on supply capability of purchased scrap, shown in Equation (9). The pair of the equations means that (1) demand price of purchased scrap cannot exceed the sum of its supply price and a windfall profit and (2) the demand price is equal to the sum of supply price and profit as long as a positive quantity of purchased scrap is supplied by scrap dealers.

As explained before, large-scale integrated mills decrease scrap uses in their steel-making by substituting other charge metallics for scrap, when the scrap price exceeds a level that corresponds to production costs of pig iron or directly-reduced iron; thus the following constraint is imposed on the demand price of purchased scrap:

\[ WRS = -PDP + PUS > 0 \quad \text{and} \quad WRS.RS = 0 \] (13)

In the second market, demand price of scrap is linked to the supply price by the following pair of equations:

\[ WDS = -PDS + PSS > 0 \quad \text{and} \quad WDS.DS = 0 \] (14)

The pair of equations means that (1) demand price cannot exceed the supply price and (2) both prices are equal when the demand quantity is positive.

Furthermore, the following pair of equations equates the value of home scrap generated from production of SB-LNFP to the supply price of scrap:

\[ WGS = PVS - PSS > 0 \quad \text{and} \quad WGS.GS = 0 \] (15)
Then, scrap prices in both markets are linked by the following pair of equations:

\[ WAP = -PSS + PDP > 0 \text{ and } WAP\cdot AP = 0 \]  

These equations argue that (1) demand price of purchase scrap in the first market cannot exceed supply price of scrap in the second market and (2) both prices are equal as long as purchased scrap is available to SB-LNFP producers.

Costs, and Price of SB-LNFP

The following pair of equations shows the relationship between price and costs of SB-LNFP (both expressed in terms of crude steel equivalent). In the first equation, the first term is price of SB-LNFP expressed in terms of crude steel equivalent and the second term is a windfall profit accruing to SB-LNFP producers, when the production activity level reaches the given capacity limit, shown in Equation (5). The third term is the value of home scrap generated from making a ton of SB-LNFP, the fourth term is cost of purchased scrap that is required to produce a ton of SB-LNFP and the fifth term is all other costs. The pair of equations means that (1) price of SB-LNFP cannot exceed the sum of scrap and all other costs and the windfall profit minus the value of home scrap and (2) SB-LNFP production ceases if the price cannot exceed all costs and the windfall profit minus the value of home scrap.

\[ WLL = -PCL + PKL - \rho PVS + \mu PDS + COC > 0 \text{ and } WLL\cdot LL = 0 \]  

Finally, the following pair of equations converts price of SB-LNFP expressed in terms of crude steel equivalent into the price expressed in terms of finished products:

\[ WDCL = -\phi PFL + PCL > 0 \text{ and } WDCL\cdot DCL = 0 \]
IV. Model Experiments and Historical Implications

This section illustrates how to use the scrap and SB-LNFP market model developed in the preceding section. For this purpose, we analyze how the SB-LNFP and scrap industries adjust to a sudden increase in demand for both SB-LNFP and scrap, like the one which took place in the years of 1973 and 1974.

The equations and parameters used in the following experiments are shown in Appendix 1. As indicated there, those equations and parameters are preliminary ones that can be used only for illustrative purposes. To apply the model to more rigorous quantitative analyses, they are required to be replaced by better estimates.

A. Model Experiments

The model is presented in six cases. The assumptions and results are summarized below: (See Tables 3.1 and 3.2)

Case 0

This case is a reference point, in which an 'average' picture of scrap and SB-LNFP markets of the major regions between 1972 and 1979 is reproduced.

Case 1

In Cases 1 through 5, which examine the consequences of an increased demand by comparison with the Case 0 situation, the demand function for SB-LNFP is shifted leftward by 6.6 million tons from the position in Case 0. 1/

In Case 1, unlike the succeeding cases, no upper limit constraint is imposed on either supply capability or scrap price.

1/ This is $2\sigma$, where $\sigma$ is the standard deviation of demand for SB-LNFP.
In comparison with Case 0, because of an upward shift of the demand function, demand for SB-LNFP increases from 37.3 million tons to 43.5 million tons \(^1\) and its production increases proportionately. The increased production of SB-LNFP requires more purchased scrap, which in turn pushes up the price of scrap from $111/ton in Case 0 to $181/ton. A higher scrap price results in a higher price of SB-LNFP, which increases from $342/ton in Case 0 to $408/ton.

Table 3.1: MAJOR ASSUMPTIONS OF THE MODEL

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<thead>
<tr>
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<th>0</th>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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</thead>
<tbody>
<tr>
<td>Demand for SB-LNFP</td>
<td>Standard</td>
<td>----Shifted Upward by 6.6----</td>
<td>million tons</td>
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<tr>
<td>Upper Limit Constraint of Supply Capability of Purchased Scrap (million tons)</td>
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<td>73.1</td>
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<td>None</td>
<td>73.1</td>
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<td>None</td>
<td>None</td>
<td>None</td>
<td>140</td>
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</tbody>
</table>

\(^1\) The realized increment in demand is 5.7 million tons, which is less than the leftward shift of the demand function (6.6 million tons). This is because the higher price has depressed demand.
### Table 3.2: SOLUTIONS OF THE MODEL

<table>
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<tr>
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<tr>
<td>Demand for SB-LNFP (million tons in finished products)</td>
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<tr>
<td>Scrap Generated in SB-LNFP Mills (million tons)</td>
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<tr>
<td>Demand for Purchased Scrap by SB-LNFP Mills (million tons)</td>
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<tr>
<td>Total Supply of Purchased Scrap (million tons)</td>
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<td>Scrap Released from Large-Scale Integrated Mills due to Substitution (million tons)</td>
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<td>Price of SB-LNFP ($/ton of finished products)</td>
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<td>Price of Purchased Scrap ($/ton)</td>
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<td>Windfall Profit Accruing to SB-LNFP Mills ($/ton)</td>
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<td>Windfall Profit Accruing to Suppliers of Purchased Scrap ($/ton)</td>
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Case 2

In Cases 2 through 4, upper limit constraints are imposed on both supply capability of purchased scrap and capacity of SB-LNFP production. In Case 2, the supply constraint of purchased scrap turns out to be binding; thus a windfall profit is generated and accrues to scrap suppliers. As a result, the price of purchased scrap goes up sharply from $181/ton in Case 1 to $262/ton. A higher scrap price results in a higher price of SB-LNFP, which increases from $408/ton in Case 1 to $489/ton. This illustrates the case wherein SB-LNFP producers claim that scrap prices determine SB-LNFP prices and that high prices of SB-LNFP do not benefit SB-LNFP producers because they are nothing but a reflection of high scrap prices.

Case 3

In Case 3, the upper limit of capacity of SB-LNFP production is reduced from the level set in Case 2, while that of supply capability of purchased scrap is kept unchanged. As a result, the upper limit constraint on the SB-LNFP production capacity, instead of that for purchased scrap, is now binding, and a windfall profit accrues to SB-LNFP producers. The price of SB-LNFP further increases from $489/ton in Case 2 to $525/ton. Because of a higher SB-LNFP price, SB-LNFP production is lower than in Case 2; consequently, less scrap is required and the scrap price decreases from the level in Case 2. This illustrates the case that SB-LNFP producers feel that prices of their products determine scrap prices and that the SB-LNFP industry is in good business.
Case 4

In Case 4, another constraint is introduced into the model. An upper limit constraint is now imposed on the scrap price at $140/ton, which is an estimated production cost of other charge metallics. The scrap price is thus forced to decrease to $140/ton. About 1.4 million tons of scrap is released from large-scale integrated mills as a result of substitution of other charge metallics for a part of scrap in their steel-making, and the saved scrap enters the markets of purchased scrap. Because the SB-LNFP price remains at the same level as in Case 3, the windfall profit accruing to SB-LNFP producers increases.

Case 5

To capture the consequences of an adjustment of production capacity on the part of SB-LNFP producers to an increase in demand, the upper limit constraint on their production capacity imposed in the preceding cases is eliminated in Case 5. The windfall profit, which accrued to SB-LNFP suppliers in the preceding cases, now disappears and the price of SB-LNFP decreases from $525/ton to $370/ton. A lower SB-LNFP price increases its demand and supply; more scrap is thus required and released from large-scale integrated mills, which continue to substitute other charge metallics for scrap because the scrap price still remains high enough.

B. Historical Implications

In retrospect, the year of 1974 was extremely profitable to both SB-LNFP mills and suppliers of purchased scrap. Demand for SB-LNFP including demand for exports, which had already started to increase in 1973, increased significantly in 1974. Demand for SB-LNFP in 1974 was 12% higher than the average demand in the years between 1972 and 1979. (See Table 2.5). Coupled
with the increased demand for purchased scrap by large-scale integrated mills, which also had a high demand for their products, total demand for purchased scrap in 1974 was higher by 10% than the average for the period 1972-79. As a consequence, the price of SB-LNFP represented by the rebar price in 1974 jumped to an unprecedented level that was 53% higher than the average for the period 1972-79. The scrap price was also higher by 68%. (See Table 2.7).

If the SB-LNFP and scrap industries could supply their goods without any upper limit constraints, the consequences of the increased demand for SB-LNFP on its own and scrap markets would have been those indicated by the solutions of Case 1. However, in 1974, most SB-LNFP producers experienced serious difficulties in fulfilling the increased orders for their products and in obtaining the required scrap. This experience indicates that the SB-LNFP and scrap markets in 1974 were probably like those described by the solutions in either Case 2 or Case 3 or some combination of those two cases.

As stated before, when scrap prices rise to production costs of other charge metallics, large-scale integrated mills reduce uses of scrap and increase uses of other charge metallics. The actual scrap price in 1974 or the solved scrap prices in Cases 2 and 3 were no doubt high enough to trigger such substitution. Thus, after scrap prices stayed at such a high level for some time, large-scale integrated mills started to substitute scrap for other charge metallics. The result of the substitution was probably close to the solutions in Case 4. As time passed, SB-LNFP producers started to expand production capacities to meet the higher demand. This eased the tight markets of SB-LNFP and its prices softened as illustrated by the solutions of Case 5.
The adjustment process to the high demand which started in 1973 would have been completed like the solutions in Case 5. In the middle of the adjustment process, however, the SB-LNFP and scrap industry experienced a sudden collapse of demand for SB-LNFP in 1975 and the picture of "shortages" of SB-LNFP and scrap was reversed completely.
V. Conclusion

The present paper has developed a model that analyzes the interrelationships between scrap and SB-LNFP markets. Despite some limitations, the model seems to be robust in analyzing unstable and simultaneous movements of both prices, as exemplified in the model experiments that were designed to reproduce the tight market situation in 1974. The model may be applied to other metal and scrap markets without substantial changes.

Because the present model is a static one, it aims primarily at analyzing short-run price projections; however, the model, even in the present form, provides a theoretical framework to project long-run price trends. For example, the factors that may have a significant influence on prices in the future can be incorporated into the model in the following manner.

On the part of light non-flat products, there are three most influential factors. The first is the expected growth of demand for light non-flat products, which can be incorporated into the constant terms $\lambda$ in Equation (1). Looking ahead to the mid-1980s, growth of the demand is heavily dependent upon (1) the recovery of construction and civil engineering industries in the industrial countries and (2) prospects for economic growth in developing countries where demand for light non-flat products has grown faster than general economic activities. The second influential factor is the way that SB-

---

1/ The major limitations are two. First, stock changes of both scrap and SB-LNFP are treated exogenously although stock changes can be endogenized by developing a dynamic version of the model. Second, the econometric performances of the estimated equations of demand for SB-LNFP and supply of scrap, used in the present model, are poor. Better estimates of those equations will improve the performances of the present model.
LNFP producers adjust to the changing demand the expansion (or contraction) of their production capacity, which is expressed as $\text{CUL}$ in Equation (4). The importance of production capacity as a determinant of both prices has been demonstrated in Case 3 of the previous section. The third influential factor is production costs of SB-LNFP, expressed as $\text{COC}$ in Equation (15). Projections of production costs need a detailed study of cost components.

On the part of scrap there are also three most influential factors. The first is the quantity of purchased scrap required by large-scale integrated mills, scrap-based special steel mills and iron foundries. This quantity is treated as an exogenous variable, expressed as $\text{DIP}$ in Equation (8). It will be influenced mostly by the level of crude steel production and the distribution of steel production according to type of furnace. Although prospects for growth of steel production in the market economies are still uncertain, the increasing trend of the percentage share of electric-arc furnace steel to total steel production is expected to continue at least until the mid-1980s. This trend will contribute to higher prices of both scrap and light non-flat products. The second influential factor is supply of purchased scrap, which is expressed in the supply function of Equation (2) and a given upper limit of the supply capability, i.e. $\text{CUP}$ in Equation (9). The increasing trend of the stock of obsolete scrap, which is a function of steel consumption in the past, will ease difficulties relating to supply of purchased scrap. The third factor is production costs of the competing charge metallics for steel-making, more specifically those for pig iron and directly-reduced iron. The expected production cost of these materials is linked to the maximum scrap price that triggers substitution. It is expressed as $\text{PUS}$ in Equation (12) in the model.
In conclusion, we can incorporate into the model the various factors that affect future prices of both scrap and light non-flat products in different directions. The model provides a tool with which we can measure effects of these factors on both scrap and SB-LNFP markets and examine the interrelationships among these factors quantitatively and consistently.
Appendix 1

Demand Function for SB-LNFP

Demand for SB-LNFP was approximated by the sum of 60% of total apparent consumption of small bars and light sections and 25% of total apparent consumption of wire rods. A demand function for SB-LNFP was estimated for the US, Japan and the EC separately. The endogenous variables were the Antwerp price of rebars deflated by the US Wholesale Price Index and GDP of each region. The results are as follows: 1/

\[
\begin{align*}
DFLU &= .7297 - .00641 \text{PFL} + 2.690 \ln \text{GDPU} \\
& \quad (0.0346) \quad (-1.38) \quad (0.574) \\
R^2 &= .282 \quad D-W=1.44 \quad Year = 1971-79 \\
\\
DFLJ &= -10.635 - .00549 \text{PFL} + 5.184 \ln \text{GDPJ} \\
& \quad (-.703) \quad (-1.19) \quad (1.50) \\
R^2 &= .373 \quad D-W = 1.01 \quad Year = 1971-79 \\
\\
DFLE &= -1.948 - .00363 \text{PFL} + 3.553 \ln \text{GDPE} \\
& \quad (-.0814) \quad (-.831) \quad (.664) \\
R^2 &= .153 \quad D-W=2.03 \quad Year = 1971-79 \\
\end{align*}
\]

where

- \(DFL()\) = Demand for SB-LNFP (million tons in finished steel products)
- \(PFL\) = Antwerp price ($/ton) of rebars deflated by the US Wholesale Price Index (1980 = 100)
- \(GDP()\) = GDP Index (1980=100)

Figures in parentheses are t-statistics.

1/ Obviously, the econometric performances of the estimated equations are poor. They must be improved, for example, by using local rebar prices rather than Antwerp prices and/or by introducing activity levels of construction and civil engineering industries. The equations stated above are used only for illustrative purposes.
These functions were aggregated; then, the estimation error for the mean demand (1,846 thousand tons) and the annual average for export (3,785 thousand tons) were added to the aggregate function. The demand function used in the model is as follows:

\[
PFL = 2782 - 64.4 \text{ DFL}
\]

**Supply function of Purchased Scrap**

A time series of historical data of purchased scrap is used as an exogenous variable. The supply function was estimated on scrap prices in the US, deflated by the US Wholesale Price Index. The result is as follows: 1/

\[
SP = 75.22 + .0765 \text{ PSP}
\]

\[
(7.67) \quad (.900)
\]

\[
R^2 = .119 \quad \text{D-W=1.47 \ Year = 1972-79}
\]

where

- \(SP\) = Supply of purchased scrap (million tons)
- \(PSP\) = Composite scrap price at Pittsburgh, Philadelphia and Chicago ($/ton), deflated by the US Wholesale Price Index (1980=100)

Then the difference between the supply estimated by this function and the estimated consumption of purchased scrap (14,858 thousand tons) was adjusted. The used equation is as follows:

\[
PSP = -789 + 13.1 \text{ SP}
\]

---

1/ The econometric performances may be improved by disaggregating the supply functions into those of the major steel-producing regions and/or by introducing appropriate time lags for scrap prices. Like the demand functions for SB-LNFP, the supply functions shown here are used only for illustrative purposes.
Parameters

The following parameters were used in the model:

\[ \phi = 0.8333 \]
\[ \rho = 0.2393 \]
\[ \eta = 1.0304 \]

Among these, \( \rho \) and \( \eta \) are the mean values of the actual statistics between 1972 and 1979, while \( \phi \) is based on the present author's best knowledge.
Appendix 2

A GENERAL FORM OF A LINEAR COMPLEMENTARITY PROGRAMMING PROBLEM

The model of scrap and SB-LNFP can be presented as the following linear complementarity programming (LCP) problem:

\[
\begin{pmatrix}
  w_1 \\
  w_2 \\
  w_3
\end{pmatrix}
= 
\begin{pmatrix}
  Q & 0 & A_1 \\
  0 & 0 & A_2 \\
  B_1 & B_2 & 0
\end{pmatrix}
\begin{pmatrix}
  x_1 \\
  x_2 \\
  p
\end{pmatrix}
+ 
\begin{pmatrix}
  c_1 \\
  c_2 \\
  c_3
\end{pmatrix}
\quad (A.1)
\]

\[
(w_1, w_2, w_3) \cdot (x_1, x_2, p) > 0
\quad (A.2)
\]

The first equation group in (A.1) and in (A.2)

\[
w_1 = Q x_1 + A_1 p + c_1
\quad (A.5)
\]

\[
w_1 x_1 = 0
\quad (A.6)
\]

represents the equilibrium conditions governing relations between quantity and price variables or more specifically, the demand function for SB-LNFP and the supply function of purchased scrap. The above pair of equations corresponds to the pair of equations (1) and (2) in Section III.
The second equation group in (A.1)

\[ w_2 = A_2 p + c_2 \]  
(A.7)

as in (A.2)

\[ w_2'x_2 = 0 \]  
(A.8)

represents the equilibrium conditions governing relations among price variables. This pair of equations corresponds to the pair of equations (12) through (18) in Section III.

The third equation group in (A.1)

\[ w_3 = B_1 x_1 + B_2 x_2 + c_3 \]  
(A.9)

and in (A.2)

\[ w_3'p = 0 \]  
(A.10)

represents the equilibrium conditions governing relations among quantity variables. This pair of equations corresponds to the pairs of equations (3) through (11) in Section III.

Unlike quadratic programming, 
LP does not require that:

1. \( Q \) is symmetric; and
2. \( A_1 = -B_1' \) and \( A_2 = -B_2' \)

Furthermore, the \( Q \) matrix does not need to be positive definite or positive semi-definite.

Quadratic programming is a special case of LCP where:

1. \( Q \) is symmetric; and
2. \( A_1 = -B_1' \) and \( A_2 = -B_2' \)

Linear programming is also a special case of LCP where:

1. \( Q = 0 \); and
2. \( A_1 = -B_1' \) and \( A_2 = -B_2' \)
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