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## A simulation model for the world manganese market

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Kiel Working Paper No. 170

A SIMULATION MODEL FOR  
THE WORLD MANGANESE MARKET

by  
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and  
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## Abstract

Proposals concerning the future regime to govern deepsea mining put forward at the United Nations Conference on the Law of the Sea reflect a lack of empirically based criteria, particularly with reference to the impact of seabed mining on the metal markets and the redistribution of income implied. A thorough discussion of the issues at stake evidently calls for substantial quantitative work. The aim of the present paper is to contribute to the discussion of this topic as far as the market for manganese ore is affected.

First, a dynamic commodity model for manganese is derived, specified and estimated. After establishing its recursive properties the model is then validated in historical simulation and stability analysis. Next, forecasts up to 1995 are made for supply, demand and the price of manganese. Finally, the model is simulated over alternative scenarios, in order to study the sensitivity of the manganese market to a supply shock from deepsea mining under different assumptions about the future economic environment.

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## I. Introduction: Major Features of the World Market for Manganese Ore

The market for manganese has been experiencing a long period of depressed prices both in nominal and real terms with only short-lived exceptions. Demand for manganese, primarily linked to the activity in the iron and steel industry, is suffering the consequences from the deep structural change occurring in the world steel industry for more than a decade, and also from the slow-down in general economic activity following the oil price booms of the 1970's. On the other hand, supply growing well ahead of demand for many years has contributed to enhance competition in a market formerly controlled by vertically-integrated steel firms.

In what follows a brief account will be given of the main factors determining demand, supply, and the price of manganese, embodied in the commodity model to be discussed at length in the remaining chapters of this paper<sup>1</sup>.

### 1. Demand Pattern and Price Trends

Manganese is principally used as an alloying element in the production of steel which accounts for about 90 percent of manganese consumption. Other important uses are dry-cell batteries, chemicals and non-ferrous alloys.

The application of manganese in the production of steel is related to its effects as desulfurizator, deoxidizator, and inhibitor of grain-boundary carbide formation. It also has the property of imparting strength, toughness, hardness and hardenability to steels. Depending on the manganese content of the iron ore used as an input in the production of pig iron, manganese can be added to the blast furnace together with iron ore in form

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<sup>1</sup> For a detailed exposition of the manganese market the reader is referred to Foders and Kim (1982).



of manganese ore or, alternatively, in a later production stage of steel in form of ferromanganese or some other manganese alloy. Blast furnace additions of manganese require low grade ores, whereas standard high-carbon ferromanganese is obtained by smelting high grade manganese ores. Processing pig iron into crude steel drastically reduces the concentration of manganese. Therefore, to compensate for this, ferromanganese is usually added to molten steel in the ladle. This constitutes the bulk of the manganese added to steel. Hence manganese ore is directly used to produce pig iron and ferromanganese but only indirectly in the production of steel. In fact the biggest share of manganese ore consumption pertains to the production of pig iron and ferromanganese<sup>1</sup>.

In the short and medium runs virtually no substitutes for manganese can be found, considering its technical and economic advantages, particularly in steel making. To a limited extent, though, titanium, zirconium, chromium, molybdenum, and nickel could assume some of the functions of manganese in this end-use. However, mainly for cost reasons manganese has no serious challenger and is in turn often being used as a substitute for, say, nickel, for example in the production of austenitic stainless steels. The most promising way to significantly reduce the consumption of manganese in steelmaking could be an improved process efficiency and the adoption of process routes with lower manganese requirements.

As has been said above, manganese is consumed predominantly in form of ferromanganese. This technical feature determines a distribution of country shares in the world apparent consumption of manganese ore different from the distribution of country shares in the world production of crude steel, which means that big steel producers are generally big consumers of ferromanganese but not necessarily big consumers of manganese ore. Average shares for the 1970's indicate that 15 percent were consumed in Japan, 13 percent in the EEC (9 countries), and only 5 percent

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<sup>1</sup> On this see National Materials Advisory Board (1981).

in the US, the corresponding shares in steel production being 16, 21 and 19 percent, respectively. In order to achieve such a high share in steel production the US substitutes imports of ore for imports of ferromanganese.

Developed countries have a share of about 90 percent in world consumption, 50 percent pertaining to market economies and 40 percent to centrally-planned economies. Nevertheless, LDCs have been experiencing a rapid increase in their share from about 1 percent in 1950 to 12 percent in 1980, and are expected to maintain their high growth rates in the future.

One of the factors that will significantly determine the future consumption pattern is, of course, the future price level. Unlike other metals, like copper, lead, zinc or tin, manganese shows a relatively stable price in the short term, as a consequence of the typical practice of pricing under annual or longer term contracts. In this century, manganese experienced only three periods of constantly rising prices, two of which were associated with wars. The first strong price rise took place during the Second World War, after a long period of falling prices due to the 1929 world economic crisis. The second price rise accompanied the Korean War and the Suez Crisis. Finally, the third one occurred after the oil price boom in 1973.

Following the market's proven sensitivity to international tensions the USGSA (General Services Administration) started to build up a strategic stockpile of manganese ore that reached its highest level in the first half of the 1960's; by 1964 GSA held a quantity almost equal to world production in 1960. After 1965, GSA began with its depletion policy for manganese, the highest disposals being registered immediately after the first oil price boom. After 1975 the stockpile's level amounted to 15 - 20 percent of world production.

Parallel to the establishment of a strategic stockpile US steel firms developed mining interests in Brazil and in Gabon adding substantial potential supply to a market already suffering from over-supply in peace times.

## 2. Supply and Reserve Patterns

World production of manganese ore expanded during the 1950's with an average rate of 12 percent, whereas apparent consumption in the most important consumer countries grew by only 9 percent per year. Toward the end of the period commercial stocks, especially in producer countries, had been built up, which, together with falling prices since 1957, reduced production growth in the 1960's to about 4 percent per year. The continued downward trend of the manganese price slowed down production again in the 1970's when the average growth rate reached 2 percent.

The Soviet Union, South Africa and Gabon are the most important producer countries of manganese ore. The role played by LDCs as manganese producers has constantly diminished. Their share in world production fell from 33 percent in 1950 to 26 percent in 1980. Due to high production costs and, partly, to reserve depletion production in India, Ghana and Morocco decreased drastically. On the other hand, new mines were opened in Australia, Brazil, Gabon, and Mexico. Output in South Africa showed a relatively high growth rate in the last 20 years (average output in the 1970's about 5 million tons), in spite of the depressed price. This country evidently managed to reduce its production costs through greater efficiency. South Africa has the biggest share (1981: 22 percent of world terrestrial reserves) in manganese ore reserves located in the Western Hemisphere<sup>1</sup>. Australia, Gabon and Mexico, too, have expanded production very fast in the 1970's. These countries are not as richly endowed with reserves

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<sup>1</sup> See National Materials Advisory Board (1981, p. 33, Tables 3 - 7). The figures referred to in this paper represent the sum of 'measured', 'inferred' and 'indicated' reserves.

like South Africa, their share being about 5 percent (1981), and their average output in the 1970's about 1.6, 2.0 and 0.5 million tons, respectively. The largest terrestrial reserves are located in the Soviet Union, the country with the highest average output registered in the 1970's, namely about 8.5 million tons.

Total terrestrial reserves in the world amount to 4,124 million tons (1981) from which only 22 percent are recoverable. The ocean bed manganese reserves in the Clarion-Clipperton area of the Northeast Equatorial Pacific are estimated to reach 500 million tons of recoverable manganese. Thus, assuming a static environment with no technical progress, and an average growth rate of world production of 5.8 percent (corresponding to the period from 1950 to 1980), recoverable reserves (terrestrial and seabed) would last 34 years. However, recoverability of reserves tends to improve with technology, which, in turn, is a dynamic phenomenon, so that the above depletion period can only be the lower point of a wide range.

## II. Derivation, Specification and Estimation of an Econometric Model for the World Manganese Market

The pioneer dynamic commodity model for manganese was built by Adams for UNCTAD and published in 1974. Two years later Charles River Associates Inc. presented another econometric model for the manganese market (1976) that has recently been updated and modified (1982). Our model differs in several ways from the UNCTAD and CRA models. First, our model postulates the manganese market as being competitive at the world level. Second, our model is medium-sized with twelve equations, only three of them being identities. Supply and demand are split up in single producer and consumer countries in a balanced manner, including the socialist countries. Finally, no generated or artificial data has been used to estimate our model, the complete data base consisting of published original statistical material.

This chapter is dedicated to the presentation of a dynamic commodity model that embodies the relevant features of the world market for manganese ore described in Chapter I. The first section deals with the theoretical and empirical justification for the estimates introduced in section 2.

### 1. Analytical Derivation and Specification

The general form of the supply equations that reflect the behaviour of manganese ore land-based producers is assumed to be

$$(1) \quad Q_t = f(P_{t-1}, Z_{t-1}, Q_{t-1}),$$

where  $Q_t$  = current manganese ore production,

$Q_{t-1}$  = manganese ore production, lagged one year,

$P_{t-1}$  = lagged price,

$Z_{t-1}$  = lagged activity variable.

The inclusion of an activity variable in production equations reflects institutional arrangements common in the manganese market, namely long term contracts, which induce a long term adjustment of ore producers to both consumption level and growth. Also, although to a lesser extent, the dependence of ore output on consumption patterns can be explained by the existence of some vertically integrated steel firms which mine their own manganese and iron ores.

The presence of lagged production and price in the supply side equations is a consequence of the underlying distributed lag structure. Contrary to Burrows' findings (1971a, b) that in the case of the mineral markets Koyck-lags assuming geometrically declining weights do not perform as well as lags of the V-inverted kind, we found the former to be clearly superior for the manganese market. A geometrically distributed lag of the Koyck-type can easily be derived starting from

$$(2) \quad Q_t = b_1 + b_2 \sum_{i=1}^{\infty} \lambda^i P_{t-i}$$

where  $\lambda^i$  is the price weight in time period  $t-i$  and  $\lambda$  is subject to the constraints  $0 \leq \lambda < 1$ . Lagging equation (2) one period and multiplying by  $\lambda$  we obtain

$$(3) \quad \lambda Q_{t-1} = \lambda b_1 + b_2 \sum_{i=2}^{\infty} \lambda^i P_{t-i}$$

Subtracting (3) from (2) and solving for  $Q_t$  yields

$$(4) \quad Q_t = (1 - \lambda) b_1 + b_2 P_{t-1} + \lambda Q_{t-1}$$

However, for estimation it is convenient to write equation (4) as

$$(5) \quad Q_t = a_1 + a_2 P_{t-1} + a_3 Q_{t-1} + \sum_{j=4}^h a_j (z_t^j + z_{t-1}^j) + u_t$$

where  $a_1 = (1 - \lambda) b_1$ ,  
 $a_2 = b_2$ ,  
 $a_3 = \lambda$ ,  
 $z_t^j$  and  $z_{t-1}^j$  are exogenous variables subject to  
 $z_t^j = 0$ , if  $z_{t-1}^j > 0$  and vice versa,  
and  $u_t$  is a stochastic disturbance.

The demand side equations of the dynamic model for the manganese market have the following general formulation

$$(6) \quad D_t = g(P_{t-1}, T, Z_t)$$

where  $T$  is a trend variable and  $Z_t$  a current activity variable. Most of these equations show consumers reacting to price with a one year lag; only in one case a Koyck-lag was preferred. As has been explained in Chapter I, the demand for manganese ore is a function of the production of pig iron and ferro alloys. Thus the correct dependent variable for the demand equations should be the consumption of manganese ore as an input to the production of pig iron and ferro alloys. Unfortunately, with the only exception of the US, no such data have been published for other, more important consumer countries like Japan and Western Europe. Instead, we could have used apparent consumption as a proxy if it were not ruled out by the fact that our price equation was specified including the ratio of total demand to total production which, in the case of demand being equal to apparent consumption, is equal to one. This happens because total apparent consumption is always identical with total production. Therefore, we had to take the only data available, namely imports, as a proxy for consumption, in spite of the problem that imports also include inventories. Due to the latter problem, for some countries the relationship between imports and the activity variable is weakened.

The price equation put forward in this study describes how the manganese price results from the interplay of two kinds of inventory changes and other exogenous variables. One type of inventory holdings considered are commercial inventories held in the Western world. The second type is given by the official USGSA stockpiling program. It is hypothesized that a flow adjustment scheme is appropriate in the former case and a stock adjustment scheme in the latter.

In the case of commercial inventories, and in accordance with standard market equilibrium theory, an excess demand will drive the price up and an excess supply will drive the price down. Generally the effect of an excess demand or excess supply is modelled as a flow adjustment process in terms of the ratio of inventory level to consumption<sup>1</sup>. In our model the changes in world commercial stocks are approximated by the ratio of total imports (as demand) to total consumption, representing the so-called market pressure, for which a positive sign is expected.

We may recall that the purpose of the GSA's stockpile program is to guarantee a constant availability of the metal in question, given US consumption and enough reasons for an eventual supply disruption. Then, following the demand-for-inventories approach, a stock adjustment scheme would require the level of the current GSA stockpile to be a function of expected future consumption and price:

$$(7) \quad GSA_t = f(\overline{CUS}_t, \overline{PUS}_t).$$

Assuming naive expectations for consumption ( $\overline{CUS}_t$ ) and price ( $\overline{PUS}_t$ ) the above relationship can be inverted so that

$$(8) \quad PUS_t = g(GSA_t, CUS_t)$$

---

<sup>1</sup> See, for example, the model for tin built by Desai (1966) and the model for copper by Fisher, Cootner and Baily (1975).



where PUS and CUS are current observable variables. Given the politically motivated necessity of holding a manganese stockpile, GSA ought to buy when the price falls in order to reach the stockpile objective and to dispose of manganese whenever supply disruptions or other reasons bring about an excess demand situation and, consequently, higher prices. Hence, we expect a negative sign for the coefficient of the variable representing the GSA stockpile level.

As a result, we get the following price equation

$$(9) \quad P_t = a + b \left(\frac{m}{q}\right)_{t-1} - c \text{GSA}_t + \sum_{i=1}^h d_i X_i + u_t$$

where  $P_t$  = current price of manganese ore,

$\left(\frac{m}{q}\right)_{t-1}$  = lagged changes in commercial stocks,

$\text{GSA}_t$  = current GSA stockpile level,

$X_i$  = exogenous variables (price of iron ore as a complement for manganese in the production of pig iron, and a time trend).

## 2. Model Estimation

Our model for the world manganese market counts twelve equations. World production of manganese could be estimated for both important producers in the West, Australia and South Africa, for the Soviet Union, and for other countries, particularly LDCs, in aggregated form. Demand as imports was estimated for Western Europe, Japan, the US, and, in aggregated form, for other countries. In addition, the model includes a price equation and three identities.

Since our model is recursive<sup>1</sup>, the structural form of the nine equations was estimated with OLS using a data sample going from 1957 to 1977.

Manganese Ore Production, Australia

$$\text{MPAU}_t = -2994 + 8.730 P_{t-1} + 68.64 T_t + 4.092 \text{FPTO}_{t-1}$$

(4.78)      (2.64)      (2.38)      (1.49)

$$\bar{R}^2 = 0.901 \quad \text{DW} = 2.22$$

- where
- $\text{MPAU}_t$  = current manganese ore production in Australia, in tons of ore weight,
  - $P_{t-1}$  = lagged real price of manganese ore, cif New York, deflated by the UN-Export Price Index (1950 = 100), in US \$/ton,
  - $T$  = trend variable,
  - $\text{FPTO}_{t-1}$  = lagged world production of pig iron and ferro alloys, in tons.

This equation shows that Australian producers respond to the lagged price, to the lagged activity variable, and to the trend, although the price is the only statistically significant variable.

Manganese Ore Production, South Africa

$$\text{MPSA}_t = -1914 + 5.802 P_{t-1} + 0.6716 \text{MPSA}_{t-1} + 7.059 \text{FPTO}_t$$

(1.95)      (1.18)      (6.16)      (2.94)

$$\bar{R}^2 = 0.971 \quad \text{DW} = 1.52 \quad \text{D (h)} = 1.23$$

- where
- $\text{MPSA}_t$  = current manganese ore production in South Africa, in tons.

---

<sup>1</sup> See Section 3 of this chapter and Appendix I for a discussion of the recursive properties of our model.

South Africa adjusts its production to past price following a Koyck distributed lag structure. Both the lagged dependent variable and the activity variable are significant. The price was not dropped because it contributes to the goodness of fit of this equation. Since a lagged dependent variable appears on the right side of the equation, the Durbin-Watson statistic is biased. Therefore the Durbin-h statistic is also provided; it indicates no serial correlation of stochastic disturbances in this case.

Manganese Ore Production, Soviet Union

$$\text{MPSO}_t = 945.6 + 0.8169 \text{MPSO}_{t-1} + 1.401 \text{FPTO}_{t-1}$$

(1.77)      (6.19)                      (1.02)

$$\bar{R}^2 = 0.922 \quad \text{DW} = 0.96 \quad \text{D (h)} = 2.88$$

where  $\text{MPSO}_t$  = current manganese ore production in the Soviet Union, in tons.

The Soviet Union, the biggest producer in the world, follows a distributed lag structure of the Koyck-type to adjust current production. In contrast with South Africa, Soviet producers do not react to price but to past production of pig iron and ferro alloys. However, the Durbin-h statistic diagnoses the existence of autocorrelation. Nevertheless, we decided to keep the OLS estimate in the model, on the grounds that alternative estimates of this equation using weighted least squares and the instrumental-variable technique showed an inferior performance in the historical simulation.

Manganese Ore Production, Other Countries

$$\text{MPOT}_t = 2640 + 0.5822 \text{MPOT}_{t-1} + 1.265 \text{FPTO}_{t-1}$$

(2.09)      (2.70)                      (0.63)

$$\bar{R}^2 = 0.424 \quad \text{DW} = 1.54 \quad \text{D (h)} = 3.89$$

where  $\text{MPOT}_t$  = current manganese ore production in other countries, in tons.

This equation describes the behaviour of manganese ore producers in LDCs, particularly in Brazil, Gabon und Mexico who, like the Soviet Union, adapt current output to past production of pig iron and ferro alloys. The OLS estimate presented here is evidently of poor quality, considering the low goodness of fit and the presence of serially correlated disturbances. In spite of this, it still turned out to be superior in the context of historical simulation compared to alternative estimates.

Manganese Ore Imports, Western Europe<sup>1</sup>

$$\text{MMEU}_t = 2715 - 14.27 P_{t-1} + 69.43 T_t$$

(3.32) (2.86) (3.46)

$$\bar{R}^2 = 0.84 \quad DW = 1.35$$

where  $\text{MMEU}_t$  = current imports of manganese ore into Western Europe, in tons.

Western European consumers adjust their imports to the lagged real price of manganese ore, since most trade is carried out in form of annual contracts, negotiated on the basis of the old price. The inclusion of an activity variable in this equation did not enhance its statistical quality. From this it can be inferred that inventories could be disturbing the relationship between imports and consumption in Western Europe.

Manganese Ore Imports, Japan

$$\text{MMJA} = 1661 - 4.620 P_{t-1} - 104.7 T_t + 59.63 \text{FPJA}_t$$

(3.14) (1.42) (9.99) (4.13)

$$\bar{R}^2 = 0.97 \quad DW = 1.30$$

where  $\text{MMJA}_t$  = current imports of manganese ore in Japan, in tons,

$\text{FPJA}_t$  = current production of pig iron and ferro alloys in Japan, in tons.

<sup>1</sup> Austria, Belgium, Denmark, F. R. of Germany, France, Greece, Ireland, Italy, Luxembourg, Norway, Portugal, Spain, Switzerland, Turkey, United Kingdom.

Japanese imports, the most important ones after the European, are determined by the lagged price and the activity variable corresponding to this country. Also a trend seems to capture quite well other influences. A comparison of this equation with the one for Western Europe leads us to infer that, because of the strong link between imports and the activity variable observed for Japan, this country seemed to hold much less inventories of manganese than the countries of Western Europe.

Manganese Ore Imports, United States

$$\begin{aligned} \text{MMUS}_t = & 1931 + 0.4080 \text{MMUS}_{t-1} - 6.960 P_{t-1} - 40.21 T_t + \\ & (1.79) \quad (2.39) \quad (1.44) \quad (1.74) \\ & 0.060 \text{GSA}_t \\ & (1.94) \end{aligned}$$

$$\bar{R}^2 = 0.65 \quad \text{DW} = 1.64 \quad \text{D (h)} = 1.25$$

where  $\text{MMUS}_t$  = imports of manganese ore into the US, in tons.

The OLS-estimate for demand as imports in the United States is the only demand equation in the model featuring a distributed lag of the Koyck-type. US-importers adjust to past price and follow a long term trend. Again this equation shows the power of demand for inventories in de-linking imports from direct consumption. As has been said before, in the case of the US not only commercial inventories but also the official stockpile program by the GSA has to be considered.

Manganese Ore Imports, Other Countries

$$\begin{aligned} \text{MMOT}_t = & -611.3 + 83.57 T_t \\ & (2.53) \quad (8.01) \end{aligned}$$

$$\bar{R}^2 = 0.72 \quad \text{DW} = 1.56$$

where  $\text{MMOT}_t$  = current imports of manganese ore by other countries, in tons.

This equation shows the import behaviour of other western countries, particularly LDCs, with respect to manganese ore.

Real Price of Manganese Ore

$$P_t = 133.07 + 2.1747 PFO_t + 67.8599 MFTO_{t-1} - 0.0028 GSA_t - 5.2992 T_t$$

(3.65)
(3.49)
(1.60)
(2.77)
(10.95)

$$\bar{R}^2 = 0.913 \quad DW = 1.27$$

- where
- $P_t$  = current price of manganese ore, cif New York, deflated by the UN-Export Price Index (1950 = 100), in US \$/ton,
  - $PFO_t$  = current price of iron ore, cif New York, deflated by the UN-Export Price Index (1950 = 100), in US \$/ton,
  - $MFTO_{t-1}$  = lagged changes in commercial stocks,
  - $GSA_t$  = current level of the US GSA stockpile, in tons.

Prices are competitively determined in the world manganese market by the price of iron ore, the closest complement to manganese ore in the production of pig iron, by lagged changes in commercial stocks, by the absolute current level of the GSA stockpile, and by a trend. Since almost no price differential can be found between the London and the New York prices, at least for the last thirty years, either cif price can be used. All signs resulted as expected. Although the lowest statistical significance is borne by the market pressure variable, MFTO, this variable contributes positively to the goodness of fit of the equation.

Finally, the model is closed with three identities:

World Manganese Ore Production

$$MPTO_t = MSAU_t + MPSA_t + MPSO_t + MPOT_t + S_t$$

- where
- $MPTO_t$  = current world production of manganese ore, in tons,
  - $S_t$  = policy variable for the study of an exogenous supply shock due to the start up of seabed mining.

World Manganese Ore Imports

$$\text{MMTO}_t = \text{MMEU}_t + \text{MMJA}_t + \text{MMUS}_t + \text{MMOT}_t$$

where  $\text{MMTO}_t$  = current world manganese ore imports.

Changes in Commercial Stocks

$$\text{MFTO}_t = \text{MMTO}_t / \text{MPTO}_t.$$

Since the last identity, corresponding to the market pressure variable, is non-linear, in some instances it is convenient to substitute for a linearized version including the same endogenous variables. We will use the linearized version in Appendix I and Chapter III only in the analysis of recursive and stability properties of the model. The following linearized identity obtains after historical simulation has been run with the original non-linear identity:

$$\text{MFTO}_t = \text{MMTO}_t + \text{MPTO}_t + M$$

where M is an exogenous variable calculated from the historical simulation results to balance the equation.

3. How the Model Works: Recursive Properties

The model for the world manganese market presented in this paper belongs to the family of equation systems with a recursive structure<sup>1</sup>. This means that a hierarchical relationship prevails among the equations, such that no equation includes endogenous variables which appear as dependent variables in higher-numbered equations.

<sup>1</sup> See Appendix I for a discussion of formal properties of recursive models like a triangular matrix of structural-form coefficients on current endogenous variables and a diagonal variance-covariance matrix of stochastic disturbance terms.

The way this recursive system functions can best be seen from Figure 1 where the unilateral flow of causation from lower-numbered to higher-numbered equations is represented in terms of a flow-diagram. The initial values of the lagged endogenous variables (production, price of manganese ore, and changes in commercial stocks<sup>1</sup>) determine, together with the relevant values of the exogenous variables (production of pig iron and ferro alloys, price of iron ore, and USGSA stockpile level), the values of the current endogenous variables (production, imports, and price of manganese ore). These values of the current endogenous variables in time period  $t$  are used as lagged values for the same variables in the determination of the current endogenous variables in time period  $t+1$ . First, the values of the production from land-based sources and of the imports by countries are calculated. Next, total production and total imports are computed, so that the ratio of both can be calculated in the following step. This ratio then enters the price equation where the price in the next period is determined which, in turn, is used to compute production and imports for the following period, and so on.

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<sup>1</sup> It should be recalled that the ratio of total imports to total production is used in our model as a proxy for the changes in commercial stocks.



Flow Diagram of Simulation Model for the World Manganese Market

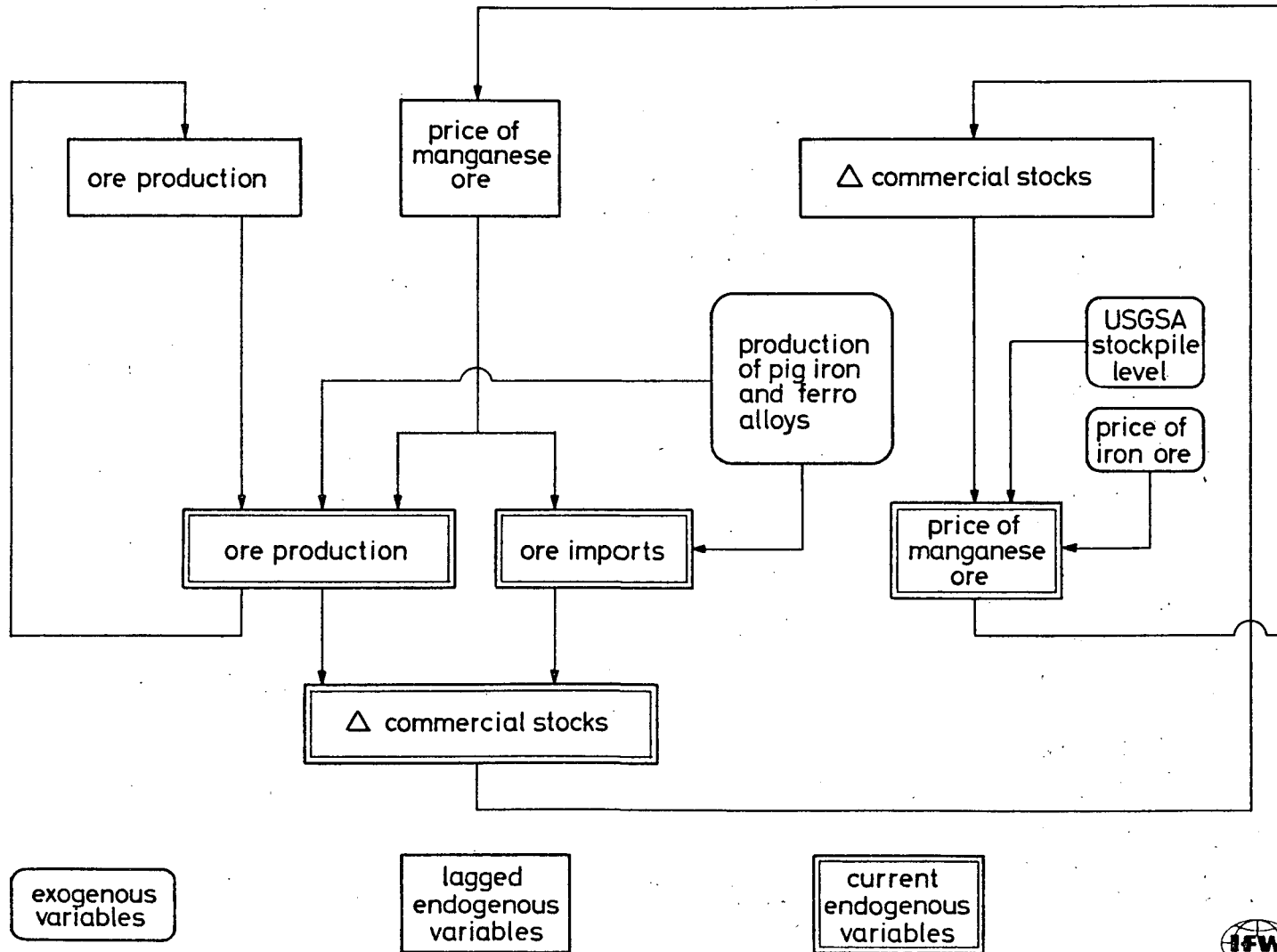


Figure 1  
Flow Diagram of Simulation Model for the World Manganese Market

### III. Model Validation

Having presented our model of the manganese market in Chapter II we now turn to two important aspects of model validation. In the first section of this chapter the performance of the estimated model in forecasting the sample period is assessed. Next, the dynamic behaviour of the model is investigated. Both tests are necessary in order to qualify the reliability of the ex ante simulation experiments to be presented in Chapter IV.

#### 1. Historical Simulation

Historical simulation was carried out not only for the estimation period (1957 - 1977) but also up to 1980, in order to check the ex post forecasting performance of our model in the years from 1978 to 1980. In addition to this, the sensitivity of the used error criteria (RMSE and turning-point prediction) with respect to alternative initial points in time for the dynamic historical simulation (1957, 1961, 1965) is analyzed<sup>1</sup>.

##### a. Manganese ore Production

As the result in Table 1 shows, the long-run trend of manganese ore production of the world, which has increased from the level of 13 million tons in 1957 to 25 million tons in 1980, can be quite closely traced by our model. The simulated production starts from 12 million tons in 1957 to reach 25 million tons in 1980 - the same level as the actual one. The root-mean-square error (RMSE) of simulation is around 1 million tons while the root-mean-square percentage error (RMSPE) is 5.6 percent.

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<sup>1</sup> Alternative initial (exogenous) values for the lagged endogenous variables bring about significantly different dynamic ex post simulation results, if the predictive power of the model is weak.

As the length of the simulation period is varied, the error tends to increase both in absolute and in relative terms. This means that the forecasting power of the present model is stronger for the earlier rather than for the later period's observations. Yet, the difference among the simulation results of different lengths is not so significant: whether the ex post simulation starts from 1961 or from 1965, the simulated results converge within 7 to 8 years to those carried out from 1957.

Actual production declines five times during the 23-year period between 1957 and 1980, while simulated production during the same period does not reveal great fluctuations. Thus, the current model can correctly forecast the upward trend in the level of world production (Figure 2). This result had been expected since dummy variables, necessary to generate the said turning points related to non-economic forces, were deliberately omitted. World production of manganese ore broken down by countries is presented in Table 2. For single producer countries the sample period forecasts show RMSPEs much lower than the ones for aggregated production, the only exception being the equation for Australia.

#### b. Manganese Ore Imports

The actual world imports of manganese ore have grown from around 5 million tons in the late 1950's to the level of around 10 million tons in the late 1970's, a period during which world imports show more often annual fluctuations than the world production of manganese ore. Revealing a slightly lower power of prediction, the ex post simulation has shown RMSE of 830 thousand tons and RMSPE of 11 percent around the actual level (Table 1). During the period between 1957 and 1980, the model under consideration could correctly forecast most turns in the level of the world imports of manganese ore (Figure 2).

In contrast to the ex post simulation of world production, the power of prediction tends to get improved when the simulation is carried out for shorter periods. Whether the experiment starts

from 1961 or from 1965, the simulation result begins to copy at the latest from the late 1960's what has already been reported for the case starting from 1957. Hence the given model reproduces best the more current observations, again due to the lack of dummy variables referred to above. Again, looking at imports by countries (Table 3) reveals which equations are responsible for the registered forecast errors.

### c. Commercial Inventories

The import-production ratio, used in this study as a proxy for changes in commercial stocks, while showing some variations over the years, has grown steadily from the late 1950's on until the early 1970's, when the price of manganese ore hit its lowest mark. Since then, the ratio of import to production has declined more or less continuously. This long-run trend is closely traced by the ex post simulation, while some extreme values of the actual ratio have been mitigated (Table 1). The RMSE of the simulation results amounts to .045 million tons and the corresponding RMSPE to 10 percent, which should be considered a good simulation performance of the model in view of the fact that the variable concerned is a ratio and not an absolute value. During the whole period of simulation between 1957 and 1980, the model has correctly predicted almost 70 percent of the turning points in the level of the import-production ratio.

The reduction in the period of simulation enhances the forecasting power of the model: When the simulation is carried out from 1961 and 1965, the RMSEs of simulation are .035 and .030 million tons, respectively, while the corresponding RMSPEs are 7.8 percent and 6.3 percent. In terms of the prediction of turning points and absolute levels of variables, all three experimented periods provided identical results from 1968 on.

Table 1 - Historical Simulation: Aggregated Results

Year	Manganese Production (1000 tons)			Manganese Imports (1000 tons)			Changes in Commercial Inventories (1000 tons)			Manganese Price (US \$/ton)						
	Actual	Simulated			Actual	Simulated			Ac- tu- al	Simulated			Ac- tu- al	Simulated		
		I	II	III		I	II	III		I	II	III		I	II	III
1957	12 894	12 407			5 599	4 039			.4343	.33			150	130.8		
58	12 775	13 033			4 067	4 232			.3184	.32			124	116.7		
59	12 950	13 119			4 642	4 748			.3585	.36			103	109.9		
60	12 399	13 560			5 492	5 143			.4430	.36			96	103.7		
1961	13 588	14 254	13 431		6 807	5 637	5 885		.5009	.40	.44		93	97.8	102.1	
62	14 273	14 569	14 197		5 228	5 974	5 904		.3663	.41	.42		90	89.7	92.6	
63	14 889	14 832	14 640		5 703	6 352	6 282		.3830	.43	.43		81	84.6	85.0	
64	16 118	15 186	15 068		7 278	6 752	6 735		.4515	.44	.45		70	80.9	81.0	
65	17 774	15 901	15 831	16 509	8 827	7 065	7 060	7 586	.4966	.44	.45	.46	77	76.0	76.1	76.4
66	17 923	16 617	16 578	17 134	7 677	7 458	7 452	7 575	.4283	.45	.45	.44	75	69.3	69.4	70.4
67	17 010	17 155	17 131	17 551	7 124	8 103	8 099	8 127	.4188	.47	.47	.46	70	65.1	65.1	64.6
68	16 900	17 710	17 694	17 996	7 855	8 544	8 542	8 573	.4648	.48	.48	.48	61	60.0	60.0	59.4
69	17 448	18 360	18 349	18 576	8 128	9 360	9 359	9 385	.4659	.51	.51	.51	53	53.6	53.7	53.2
70	18 230	19 112	19 104	19 280	9 160	10 066	10 065	10 081	.5025	.53	.53	.52	48	51.3	51.3	51.0
1971	21 049	19 796	19 790	19 928	10 546	10 349	10 349	10 361	.5010	.52	.52	.52	52	49.5	49.5	49.3
72	20 823	20 188	20 183	20 293	9 768	10 383	10 383	10 392	.4692	.51	.51	.51	48	46.7	46.7	46.5
73	21 081	20 833	20 829	20 916	11 226	11 122	11 122	11 129	.5325	.53	.53	.53	45	51.8	51.8	51.7
74	22 046	21 970	21 967	22 038	11 891	10 855	10 855	10 861	.5394	.49	.49	.49	55	58.0	58.0	57.9
75	23 663	22 952	22 950	23 007	11 520	10 371	10 371	10 375	.4868	.45	.45	.45	53	62.7	62.7	62.6
76	23 946	23 180	23 178	23 224	10 921	10 153	10 153	10 156	.4561	.44	.44	.44	70	59.2	59.2	59.1
77	21 986	23 503	23 501	23 540	10 086	10 142	10 142	10 144	.4587	.43	.43	.43	65	61.8	61.8	61.8
78	20 588	23 759	23 757	23 789	8 706	9 613	9 613	9 614	.4229	.40	.40	.40	54	55.0	55.0	54.9
79	24 250	24 204	24 203	24 228	9 888	10 172	10 073	10 075	.4100	.42	.42	.42	48	47.3	47.3	47.3
80	24 748	24 560	24 559	24 580	10 418	10 394	10 397	10 398	.4200	.42	.42	.42	45	64.4	64.4	64.4
RMSE	-	1044.7	1107.6	1153.7	-	828.1	810.5	780.8	-	.045	.035	.030	-	7.68	6.91	6.72
RMSPE	-	(5.6%)	(5.7%)	(5.8%)	-	10.9%	(9.6%)	(8.7%)	-	(10%)	(7.8%)	(6.3%)	-	(12%)	(13%)	(13%)

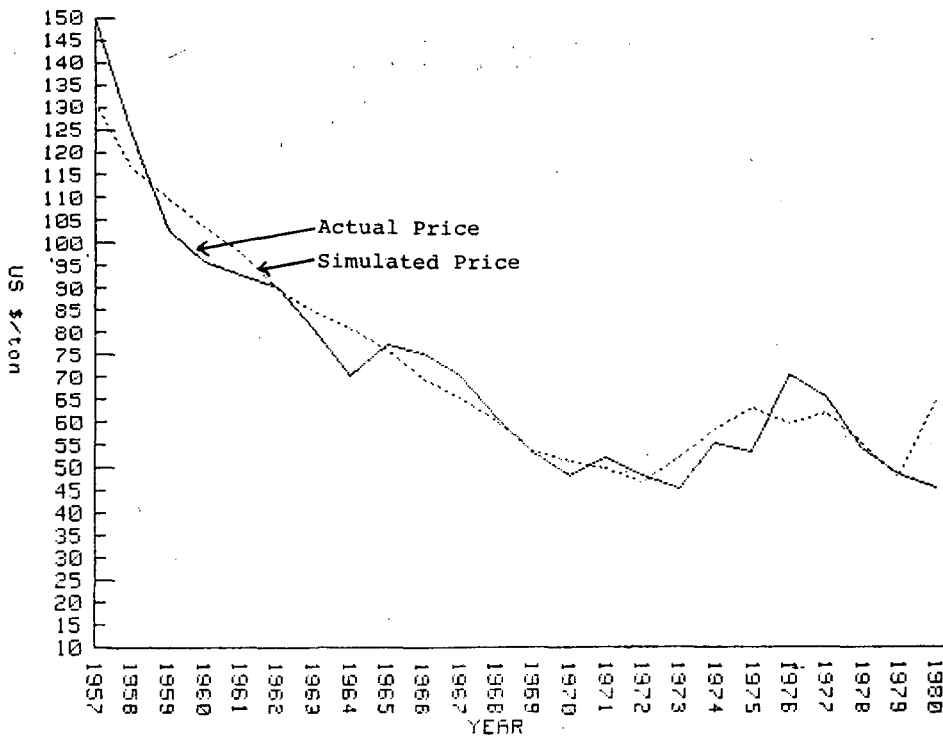
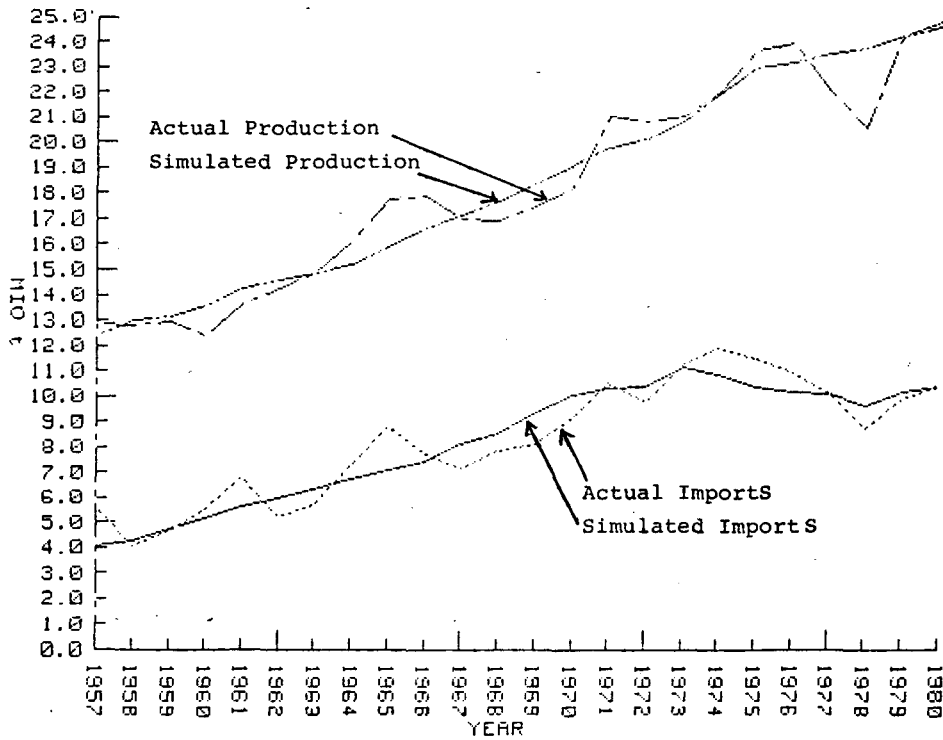
Table 2 - Historical Simulation Results by Country:  
Manganese Ore Production (1000 metric tons)

Year	Australia		South Africa		Soviet Union		Others	
	Actual	Simu- lated	Actual	Simu- lated	Actual	Simu- lated	Actual	Simu- lated
1961	89	54	1 418	1 245	5 974	6 101	6 108	6 031
62	71	160	1 465	1 287	6 404	6 281	6 334	6 469
63	37	170	1 398	1 302	6 665	6 437	6 790	6 731
64	62	226	1 321	1 360	7 152	6 582	7 583	6 901
65	102	406	1 568	1 629	7 578	6 751	8 526	7 045
66	318	535	1 693	1 958	7 707	6 924	8 205	7 160
67	569	590	1 817	2 218	7 177	7 081	7 447	7 241
68	744	683	1 972	2 474	6 566	7 230	7 618	7 307
69	890	804	2 205	2 784	6 552	7 386	7 806	7 376
70	751	937	2 680	3 161	6 843	7 553	7 956	7 453
1971	1 051	1 049	3 237	3 511	7 320	7 712	9 441	7 518
72	1 165	1 087	3 272	3 710	7 821	7 837	8 562	7 550
73	1 523	1 238	4 242	4 012	8 247	7 975	7 069	7 603
74	1 522	1 544	4 835	4 576	8 155	8 154	7 534	7 693
75	1 555	1 739	5 881	5 117	8 459	8 326	7 768	7 768
76	2 154	1 714	5 503	5 275	8 636	8 419	7 653	7 770
77	1 527	1 788	5 290	5 423	8 595	8 508	6 574	7 782
78	1 290	1 871	4 413	5 522	8 600	8 578	6 285	7 786
79	1 707	2 080	5 278	5 658	9 786	8 656	7 078	7 808
80	2 002	2 054	5 791	5 893	9 794	8 758	7 161	7 855
RMSE	234.76		421.23		547.99		840.44	
RMSPE	1.26		0.14		0.07		0.11	

Table 3 - Historical Simulation Results by Country:  
Manganese Ore Imports (1000 metric tons)

Year	Europe		Japan		U. S. A.		Others	
	Actual	Simu- lated	Actual	Simu- lated	Actual	Simu- lated	Actual	Simu- lated
1961	2 571	2 525	369	428	1 948	2 122	1 919	809
62	2 272	2 508	322	409	1 793	2 094	841	893
63	2 498	2 712	368	467	2 168	2 126	669	976
64	2 991	2 890	559	636	2 744	2 149	984	1 060
65	3 124	3 018	1 065	765	3 498	2 134	1 141	1 144
66	2 891	3 156	1 140	957	2 406	2 112	1 240	1 227
67	2 722	3 321	1 507	1 378	1 874	2 089	1 021	1 311
68	3 397	3 452	1 753	1 633	1 656	2 062	1 049	1 394
69	3 163	3 595	2 025	2 250	1 761	2 037	1 179	1 478
70	3 852	3 754	2 658	2 747	1 574	2 002	1 076	1 561
1971	4 309	3 857	3 315	2 933	1 737	1 914	1 185	1 645
72	3 766	3 953	2 981	2 920	1 470	1 782	1 551	1 729
73	4 638	4 062	3 364	3 777	1 370	1 471	1 854	1 812
74	4 908	4 058	3 908	3 672	1 111	1 229	1 964	1 896
75	4 427	4 040	3 740	3 330	1 428	1 021	1 925	1 979
76	4 342	4 042	3 355	3 186	1 195	862	2 030	2 063
77	3 324	4 162	2 754	3 056	845	778	3 163	2 146
78	3 756	4 194	2 012	2 504	563	685	2 375	2 230
79	4 375	4 500	2 746	2 533	454	560	2 314	2 481
80	4 530	4 539	2 862	2 865	629	596	2 397	2 397
RMSE	399.68		243.97		409.48		399.84	
RMSPE	0.11		0.15		0.20		0.25	

Figure 2 - Historical Simulation of Production, Imports and Price of Manganese Ore, 1957 - 1980





#### d. Price

With fluctuations of small sizes on the way, the price of manganese ore has followed a long-run trend that has declined from the high level of the late 1950's at around 150 dollars per ton to around 45 dollars per ton in the early 1970's. Such a long trend has been quite closely traced by the ex post simulation (Figure 2). While the RMSE of simulation has been 7.7 dollars, the RMSPE has been 12 percent (Table 1). Like with imports the model has correctly simulated almost 70 percent of the turning points. Even if the sensitivity of the results is tested over periods of different length, the results remain almost unchanged in both absolute and relative terms.

### 2. Dynamic Behaviour of the Model

In the last section the performance of the simulation model for the manganese market presented in Chapter II in forecasting the sample period has been qualified. However, before using the model for ex ante simulations an exploration of its dynamic response properties seems in order, as an additional validation measure. First we shall briefly review the standard stability criteria as applied to dynamic simulation models. Next, we turn to our model providing a thorough analysis of its latent roots which allows some important conclusions concerning its short-run and long-run stability.

#### a. Stability Criteria

Stability analysis deals with the problem of finding out if a given model, in our case a first-order difference equation system, is able to reach a stationary equilibrium which, at the same time, is assumed to be its final equilibrium position. In the literature clear cut stability criteria for linear models

are offered, whereas for non-linear models only extremely sophisticated criteria<sup>1</sup> can be found. Since the computational implementation of these sophisticated methods lay beyond our means we decided to perform the stability analysis on a linearized version of our model<sup>2</sup>. Thus our "second best" analysis applies only to one specific solution of the model.

Starting from the structural form of the linearized version of our model,

$$(10) \quad Y(t) = A \cdot Y(t) + B \cdot Y(t-1) + D \cdot X + U(t)$$

the corresponding reduced form obtains as

$$(11) \quad Y(t) = (I - A)^{-1} \cdot B \cdot Y(t-1) + (I - a)^{-1} \cdot D \cdot X \\ + (I - A)^{-1} U(t)$$

or, using standard notation, as

$$(12) \quad Y(t) = \pi_1 Y(t-1) + \pi_2 X + V(t)$$

where

$$\begin{aligned} \pi_1 &= (I - A)^{-1} B \\ \pi_2 &= (I - A)^{-1} D \\ V(t) &= (I - A)^{-1} U(t) \end{aligned}$$

In the non-stochastic case the term  $V(t)$  in equation (12) vanishes. What remains is a system of first order non-homogenous difference equations with the general solution

$$(13) \quad Y(t) = Y^* + E(t)$$

composed by a particular solution  $Y^*$  and a homogenous solution  $E(t)$ .

---

<sup>1</sup> For example, Lyapunov's "direct" method which serves to study the stability of difference equation systems without solving the system. On this see Gandolfo (1980).

<sup>2</sup> The only non-linear identity in the model has been substituted for a linear one involving the same endogenous variables. For details see Chapter II in this paper where the linearized version of our model was introduced.

Turning first to the particular solution to the deterministic version of the reduced form, we assume that the general solution  $Y(t)$  reaches the particular solution  $Y^*$  in both time periods  $t$  and  $t-1$ , for given  $X = \bar{X}$ . Substituting  $Y(t)$  and  $Y(t-1)$  for  $Y^*$  in equation 12 (for  $U(t) = 0$ ) yields the final form

$$(14) \quad Y^* = (I - \pi_1)^{-1} \pi_2 \bar{X}$$

which exists if the determinant to the matrix  $(I - \pi_1)$  does not vanish.

Using identity (13) the deterministic reduced form can be written as

$$(15) \quad Y(t) = \pi_1 (Y^* + E(t-1)) + \pi_2 X.$$

After some algebra and substitution of  $Y^*$  for the right-hand side of (14), and again using (13), the homogenous solution

$$(16) \quad E(t) = Y(t) - Y^* = \pi_1 (Y(t-1) - Y^*)$$

is obtained. Assuming that this homogenous solution is of the form

$$(17) \quad Y(t) - Y^* = \lambda(t) I (Y(t=0) - Y^*)$$

and equating (16) and (17) we get

$$(18) \quad \lambda(t) I (Y(t=0) - Y^*) - \pi_1 \lambda(t-1) (Y(t=0) - Y^*) = 0.$$

or

$$(19) \quad \lambda(t) (\pi_1 - \lambda I) (Y(t=0) - Y^*) = 0.$$

A non-trivial solution to (19) requires the determinant of matrix  $(\pi_1 - \lambda I)$  to vanish.

If the system is to be stable the eigenvalues belonging to the matrix of reduced-form coefficients on lagged endogenous variables ( $\pi_1$ ) have to satisfy the following conditions: real roots have to be less than unity in magnitude and complex roots have to possess each a modulus less than unity in magnitude. So, if the particular solution  $Y^*$  exists and if the latent roots of matrix  $\pi_1$  meet the required restrictions, the general solution reaches the particular solution in the limit. The fact that some of the roots may have imaginary components will bring about an oscillatory behaviour, such that the general solution will show a sinusoidal path in time.

#### b. Eigenvalue Analysis

Our twelve-equation simulation model for the manganese market appears to be quite stable for our purposes, according to the criteria established above. Table 4 shows the inverse reduced-form matrix  $(I - \pi_1)^{-1}$ , necessary for the existence of a particular solution to our system. The eigenvalues corresponding to the reduced-form matrix of coefficients on lagged endogenous variables are presented in Table 5. As can be seen, half of the latent roots are zero, four are positive and real, and two are complex. No real root takes values equal to or greater than one, whereas the modulus of the dominant complex root is substantially higher than one.

The presence of characteristic roots with an imaginary component will determine an oscillatory time-path. Furthermore, due to the value taken by the modulus of the dominant root, a constantly increasing amplitude of oscillation and, therefore, a certain instability are to be expected. However, in order to determine if this instability is of a short-run or of a long-run nature the period of oscillation<sup>1</sup> has to be calculated.

---

<sup>1</sup> The period of oscillation is defined as  $2\pi/\omega$ ,  $\omega$  being calculated from  $\gamma \cdot \cos \omega = \alpha$  or  $\gamma \cdot \sin \omega = \theta$  if our complex number is  $\alpha \pm \theta i$  and its absolute value  $\gamma = (\alpha^2 + \theta^2)^{1/2}$ .

In our case the period of oscillation turns out to be four years long. This means that, for example, if a 10-year simulation period is considered, and if the oscillation period starts with  $t=0$ , after ten years 2.5 oscillations will have taken place. Even if a 20-year period is to be simulated no more than 6 oscillations will be experienced. Thus, for our purposes, the degree of instability implied by the complex roots seems to be neglectable. If, on the contrary, a long-term simulation experiment extending over fifty or more years would be of interest, it might be preferable to reestimate some equations in the model before doing so, considering that after every oscillation the amplitude increases.

Historical simulation has shown that our model tackles quite well the difficult task of reproducing the values of the endogenous variables in spite of the many inconveniences that had to be dealt with while estimating the model. In fact, the performance is very good for a model which was estimated on the basis of proxy variables for such important variables as consumption and inventories. Furthermore, having avoided the use of dummy variables as well as of generated data the model is able to catch the outstanding features of the manganese market up to 1980. However, it has to be noted that, as always, some variables can be much better traced than others, as the simulation error criteria show.

Stability analysis also qualifies our model for prediction applications in the context of short-run or medium-run forecasts. The computation of the latent roots has helped to detect instabilities in the model which seem to force the model to an oscillatory behaviour. Nevertheless, ten out of twelve latent roots satisfy the stability criteria, so that at least in the short- and medium-runs no great instabilities should be expected.

Table 4 - Inverse Reduced-Form Matrix of Normalized Coefficients on Lagged Endogenous Variables

	I	MPAU	MPSA	MPSD	MPOT	MMEU	MMJA	MMUS	MMOT	PUS	MPTD	MMTO	MFTD
MPAU	I	0.	0.	0.	0.	0.	0.	0.	0.	8.73	0.	0.	0.
MPSA	I	0.	0.6716	0.	0.	0.	0.	0.	0.	5.802	0.	0.	0.
MPSD	I	0.	0.	0.8169	0.	0.	0.	0.	0.	0.	0.	0.	0.
MPOT	I	0.	0.	0.	0.5822	0.	0.	0.	0.	0.	0.	0.	0.
MMEU	I	0.	0.	0.	0.	0.	0.	0.	0.	-14.27	0.	0.	0.
MMJA	I	0.	0.	0.	0.	0.	0.	0.	0.	-4.62	0.	0.	0.
MMUS	I	0.	0.	0.	0.	0.	0.	0.408	0.	-6.96	0.	0.	0.
MMOT	I	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
PUS	I	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	67.86
MPTD	I	0.6716	0.8169	0.5822	0.	0.	0.	0.	0.	14.532	0.	0.	0.
MMTO	I	0.	0.	0.	0.	0.	0.408	0.	0.	-25.85	0.	0.	0.
MFTD	I	0.6716	0.8169	0.5822	0.	0.	0.408	0.	0.	-11.318	0.	0.	0.

Table 5 - Eigen-Values of Matrix of Reduced-Form Coefficients on Lagged Endogenous Variables

<u>Number</u>	<u>Eigen-Value</u>	<u>Modulus</u>
1	0	-
2	0	-
3	0	-
4	0	-
5	0	-
6/7	$-0.05 \pm 27.72 i$	27.72
8	0.90	-
9	0.27	-
10	0.82	-
11	0.58	-
12	0	-

#### IV. Forecasts and Ex Ante Simulation Experiments for the Manganese Market

In this chapter some applications of our dynamic simulation model for the manganese market will be presented. The first section deals with a forecast for the world manganese market from 1982 to 1995, under the assumption that the relevant exogenous variables follow the pattern currently expected on the basis of actual developments in the world economy.

The second section of this chapter discusses ex ante simulation results derived from alternative assumptions on the future behaviour of some exogenous variables. Attention will be paid to the impact of (1) deepsea mining, (2) a change in the stockpile program of the USGSA, and (3) a change in the price trend on supply, demand and price of manganese ore. Since we are particularly interested in the effects of the production of manganese from seabed nodules, the joint influence of deepsea mining and each one of the points referred to above under (2) to (3) will also be analysed.

##### 1. Forecast for Supply, Demand and Price of Manganese Ore, 1982 - 1995

The early 1980's are characterized by a world-wide recession which has substantially reduced the demand for raw materials in industrialized as well as in industrializing countries. One of the sectors worst hit is the steel industry which was going through a process of deep structural change even before the first oil price boom in 1973. During the mid-seventies steel production in some parts of the world, particularly Japan and Western Europe, recovered slightly until the second oil price shock, when the current slow-down in economic activity began. Thus, the demand for manganese has been very weak in the seventies and early 1980's. In spite of this, land-based production



of manganese ore continued to grow until 1976 - 1977 when it fell for two years before recovering again. This pattern of production constantly over-supplied the market, exerting high pressure on the real price which is on a downward trend since 1957/8.

Obviously, the chances for the market to recover during the 1980's are not good. Considering the said situation in the world steel industry, which accounts for the bulk of manganese consumption, even a rapid growth in world economic activity is very uncertain to bring about the rise in demand needed to reverse the price trend.

In accordance with the above description of the international scenario we assumed for the exogenous variables in our model, in particular for the production of pig iron and ferro alloys, a growth rate slowly reaching 3 percent per year in 1987, and remaining at this level from then on (Table 6). As can be seen from Table 7 our model estimates world mine production to continue its growth during the 1980's: Production starts with 24.9 million tons in 1981 and reaches 25.7 and 29.8 in 1987 and 1995, respectively, which means an average growth rate per year of 1.4 percent. The highest rates will be registered in Australia (5.2 percent) and in South Africa (3 percent). The Soviet Union and the 'other' countries, among others, Gabon, Mexico, and Brazil, are estimated to show average growth rates of production well below one percent.

Similarly, world imports are forecasted to reach the level of 12.7 million tons by 1995, starting from 10.5 million tons in 1981. From 1981 to 1987 aggregated imports will augment only insignificantly (0.3 percent per year), yet for the period 1987 - 1995 a growth rate of 1.1 per year is anticipated. The highest average growth rate will be registered in the countries labeled 'others', i. e., in the LDCs. Among industrialized countries Western Europe (2 percent) and Japan (1.3 percent) are expected to show the highest growth rates, whereas imports into the US will probably cease by 1993 or 1994. The latter is mainly due to the increasing use of foreign ferromanganese, much cheaper than domestic ferromanganese, as an input for steel production.

Table 6 - Exogenous Variables for the Base Simulation: 1982 - 1995

Year	Trend (T)	Iron Ore Price (PFO) <sup>a</sup>	US Government Stockpile (GSA) (thousand tons)	Pig Iron and Ferro Alloy Production (million tons)	
				Japan (FPJA)	World (FPTO)
1982	38	47.73	3559	87.0	506.4
83	39	47.97	3559	87.4	508.9
84	40	48.45	3559	88.3	514.0
85	41	49.18	3559	89.6	521.7
86	42	50.16	3559	91.4	532.2
87	43	51.41	3559	93.7	545.5
88	44	52.95	3559	96.5	561.8
89	45	54.54	3559	99.4	578.7
90	46	56.18	3559	102.4	596.1
1991	47	57.87	3559	105.5	613.9
92	48	59.60	3559	108.6	632.4
93	49	61.39	3559	111.9	651.3
94	50	63.23	3559	115.3	670.9
95	51	65.13	3559	118.7	691.0

<sup>a</sup> US-Dollars/ton, cif New York, deflated by the UN-Export Price Index for Manufactured Goods (1950 = 100).

Table 7 - Base Simulation Results for the Manganese Ore Market

Year	Production (1000 tons)					Imports (1000 tons)					Price (Dollars per ton)
	Aus- tra- lia	South Afri- ca	So- viet Union	Oth- ers	Total	Eu- rope	Japan	USA	Oth- ers	Total	
1981	2010	5810	9655	7449	24926	4641	2768	599	2480	10490	59.3997
82	2205	5907	9542	7617	25273	4506	2597	447	2564	10115	54.0935
83	2227	5942	9450	7715	25335	4650	2540	382	2647	10222	47.9154
84	2252	5947	9378	7775	25353	4808	2518	358	2731	10416	43.88
85	2306	5963	9327	7817	25414	4935	2509	336	2815	10597	40.6703
86	2378	6009	9295	7851	25535	5050	2527	309	2898	10786	37.9176
87	2466	6098	9284	7884	25734	5159	2572	277	2982	10992	35.7062
88	2570	6239	9294	7920	26024	5260	2645	239		11211	34.0763
89	2691	6440	9325	7961	26418	5353	2720	195	3149	11419	32.4827
90	2815	6684	9374	8007	26881	5445	2802	148	3232	11629	30.8478
1991	2940	6962	9438	8055	27397	5538	2890	100	3316	11845	29.2492
92	3068	7265	9516	8106	27956	5630	2977	51	3400	12059	27.6943
93	3198	7590	9605	8159	28554	5722	3077	2	3483	12285	26.2227
94	3332	7933	9704	8214	29184	5812	3181	-47	3567	12513	24.8473
95	3468	8293	9813	8271	29847	5901	3286	-98	3650	12739	23.5815

Over the whole period from 1982 to 1995, thus, world manganese ore production will, on average, grow by 0.3 percent over imports. We can conclude from this that average growth rates on both sides of the market will be almost equal, because increasing consumption in producer countries, especially in LDCs, is likely to account for the difference. Nevertheless, the market has been constantly over-supplied since the early seventies, so that enough inventories should be left on both sides to keep the real price of manganese<sup>1</sup> on a downward trend. Consequently, our model forecasts the price to fall from its 1981-level of 59 US-Dollars per ton (cif New York) to 35.7 in 1987 and, finally, to 23.6 in 1995.

## 2. The Impact of Deepsea Mining and Other Exogenous Influences on World Production, World Imports and Price

One of the still unsettled issues discussed at the United Nations Conference on the Law of the Sea is the regime to govern deepsea mining. Central to the regime proposed by the great majority of the countries concerned is a set of restrictive measures, considered necessary to protect land-based producers in LDCs from export revenue losses eventually incurred, if deepsea mining should someday come into being. In order to provide a sound empirical basis for discussions of this topic, we simulated our model assuming for convenience that deepsea mining will start by 1988<sup>2</sup>. Three

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<sup>1</sup> Deflated by the UN-Export Price Index for Manufactured Goods (1950 = 100).

<sup>2</sup> However, because of the uncertainty still prevailing over the property rights issue, the production of seabed nodules is much more likely to begin in the 1990's or later. Since we do not intend to forecast the long-run, 1988 was chosen as a year that allows the market to readjust from such an exogenous shock till 1992/3. Of course, our results carry over - at least qualitatively - to any later period.

scenarios of nodule production from the seabed were assumed; in the first case 2.95 million tons of manganese ore equivalent are being produced, and in the second case three times this quantity<sup>1</sup>; finally, a stepwise expansion of manganese production by yearly 1180 million tons ore equivalent was assumed, beginning with 2950 million tons in 1988 (like in the low case) and ending 1993 when the high level of 8850 million tons will be reached.

In this section, first the effects of the said scenarios on production, imports and price of manganese ore will be analyzed. In addition to this, the influence of alternative assumptions affecting the USGSA stockpile and the price trend will be assessed with and without deepsea mining. That is, the joint impact of seabed mining together with each one of the other exogenous shocks is also of interest here.

Table 8 shows the simulation results for the aggregated land-based production of manganese ore in the event of deepsea mining starting 1988. Comparison with the figures from the base simulation (Table 7) reveals that a low supply shock to the market lowers mine production by 1990, i. e., two years after the assumed starting up of nodule production from the seabed. This corresponds to the average time lag the mine production of manganese ore takes to adjust to price changes. As can be seen from Table 10 the manganese price reacts 1989, i. e., one year after the shock, determining, in turn, the production level in the next year. Although the low level of nodule production is hypothesized to remain constant from 1988 to 1995, the price-effect of the supply shock is rapidly absorbed by market adjustments, so that by the end of the period mine production is only 0.2 percent lower than in the base case (Figure 3a).

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<sup>1</sup> It is generally acknowledged that five international consortia are interested in nodule extraction from the north-east Pacific Ocean. With current technology the first generation of operations will each have a capacity between 1 and 3 million tons of nodules per year. Considering the expected manganese content of these nodules to be 0.2 million tons yields 589965 tons of manganese ore equivalent per 1 million tons of nodules. Thus, in the first of the above scenarios each mining group is assumed to own one operation with a capacity of 1 million tons per year; in the second case a capacity of 3 million tons is hypothesized.

The high seabed production scenario has, of course, a much stronger price impact than the low production scenario (Table 10). In this case the production level falls to 87.7 percent of the base case level, reaching a quantity 7.3 percent lower than in the low production scenario. By the end of the simulation period land-based production in the high nodule output scenario is 11.8 percent lower than the corresponding base case result. The third scenario considered, i. e. a stepwise expansion of manganese production, has, as expected, a relatively smooth impact on the market, its effects lying in the middle of the ones registered in the other two scenarios (Figure 4).

We will now study the joint influence of deepsea mining and a stockpile program by the USGSA on the manganese market. In the base case we assumed that the level of the stockpile remains constant from 1987 to 1995. Now, the GSA will be allowed to dispose of 250 thousand tons a year, in accordance with its policy concerning manganese implemented since 1963/4. The results in Table 10 show that the effect of such a depletion policy does not hit the price of manganese as hard as seabed mining. The real price of manganese falls by 18 percent from 1988 to 1995, if no seabed mining is assumed. This means that a disposal of the said quantity of ore by the USGSA has a stabilizing effect on the price of manganese. However, this stabilizing effect is weakened if the combined impact of this depletion policy by the USGSA and the beginning of seabed mining is allowed for. In the scenario of high seabed nodule production price falls by 36 percent in the period from 1988 to 1995. While in the scenario with no seabed mining aggregated production turns out to be higher than in the base case by 1995, the high production scenario brings about a reduction of 7.4 percent, compared with the base case. Nevertheless, this production level is higher than in any other case studied above (Figure 3b).

Table 8 - World Manganese Ore Production from Land-Based Sources in Different Scenarios Influencing the Manganese Market, 1988 - 1995 (1000 tons)

Year	Seabed Mining (SM)			Change in USGSA Stockpile Programme			No Price Trend		
	Low SM	Stepwise SM	High SM	No SM	Low SM	High SM	No SM	Low SM	High SM
1988	26025	26025	26025	26025	26025	26025	25956	25956	25956
89	26418	26418	26418	26431	26431	26431	26358	26358	26358
90	26838	26849	26773	26906	26864	26799	26851	26808	26743
1991	27343	27331	27261	27436	27382	27301	27405	27351	27270
92	27897	27866	27808	28008	27951	27862	28009	27952	27864
93	28492	28408	28397	28620	28560	28467	28658	28599	28507
94	29121	29054	29023	29266	29204	29108	29343	29283	29188
95	29783	29700	29683	29944	29881	29784	30063	30003	29908

Table 9 - World Imports of Manganese Ore in Different Scenarios Influencing the Manganese Market, 1988 - 1995 (1000 tons)

Year	Seabed Mining (SM)			Change in USGSA Stockpile Programme			No Price Trend		
	Low SM	Stepwise SM	High SM	No SM	Low SM	High SM	No SM	Low SM	High SM
1988	11211	11211	11211	11192	11192	11192	11203	11203	11203
89	11419	11419	11419	11355	11355	11355	11282	11282	11282
90	11706	11687	11821	11522	11599	11713	11353	11431	11546
1991	11929	11954	12056	11695	11779	11905	11438	11522	11647
92	12141	12195	12266	11867	11948	12071	11521	11601	11723
93	12365	12443	12489	12049	12128	12250	11614	11692	11812
94	12592	12692	12715	12235	12312	12432	11711	11786	11903
95	12817	12936	12938	12417	12493	12611	11804	11877	11991



Table 10 - Real Price of Manganese Ore in Different Scenarios<sup>a</sup>  
Influencing the Manganese Market (US-Dollar/ton)

Year	Seabed Mining (SM)			Change in USGSA Stockpile Programme			No Price Trend		
	Low SM	Stepwise SM	High SM	No SM	Low SM	High SM	No SM	Low SM	High SM
1988	34.00	34.08	34.00	34.90	34.90	34.90	39.30	39.30	39.30
89	29.50	30.25	25.00	33.90	31.00	26.50	43.10	40.10	35.60
90	27.90	26.88	23.40	32.90	30.00	25.60	46.40	43.50	39.10
1991	26.50	24.55	22.40	31.90	29.20	25.10	49.70	47.10	43.10
92	25.00	22.34	21.00	30.90	28.30	24.30	53.10	50.60	46.70
93	23.60	20.24	19.60	30.00	27.50	23.60	56.60	54.20	50.40
94	22.30	18.29	18.40	29.20	26.80	22.90	60.20	57.80	54.20
95	21.10	17.21	17.20	28.60	26.20	22.40	63.90	61.60	58.10

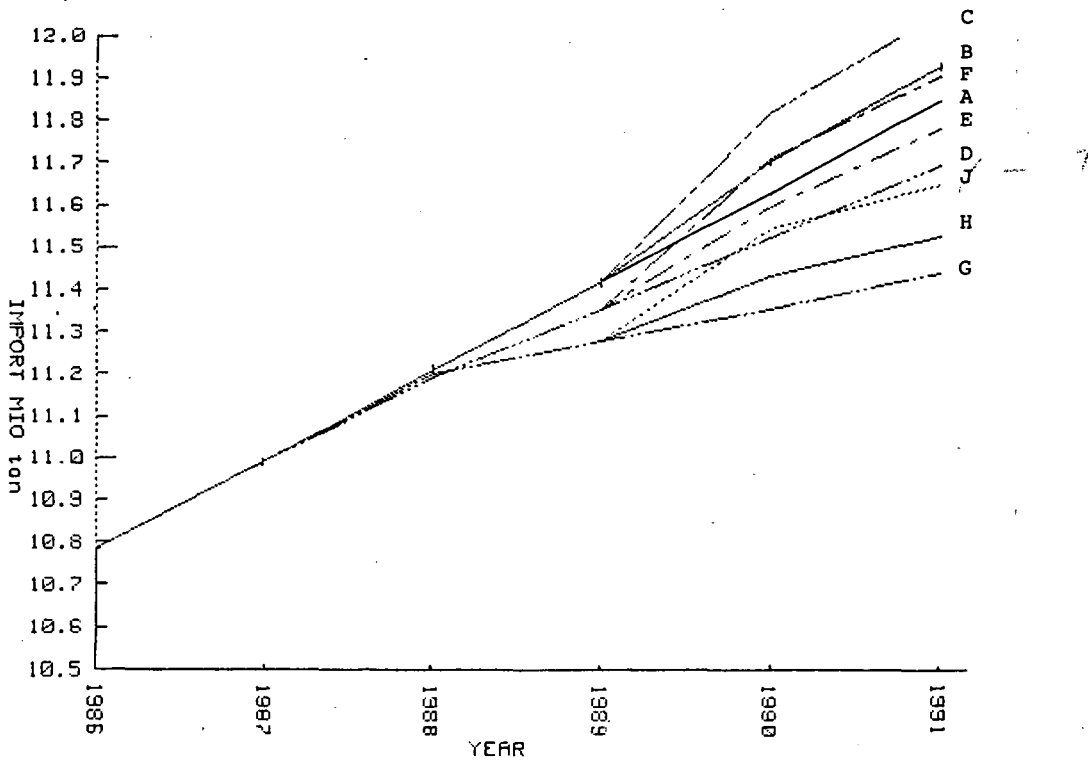
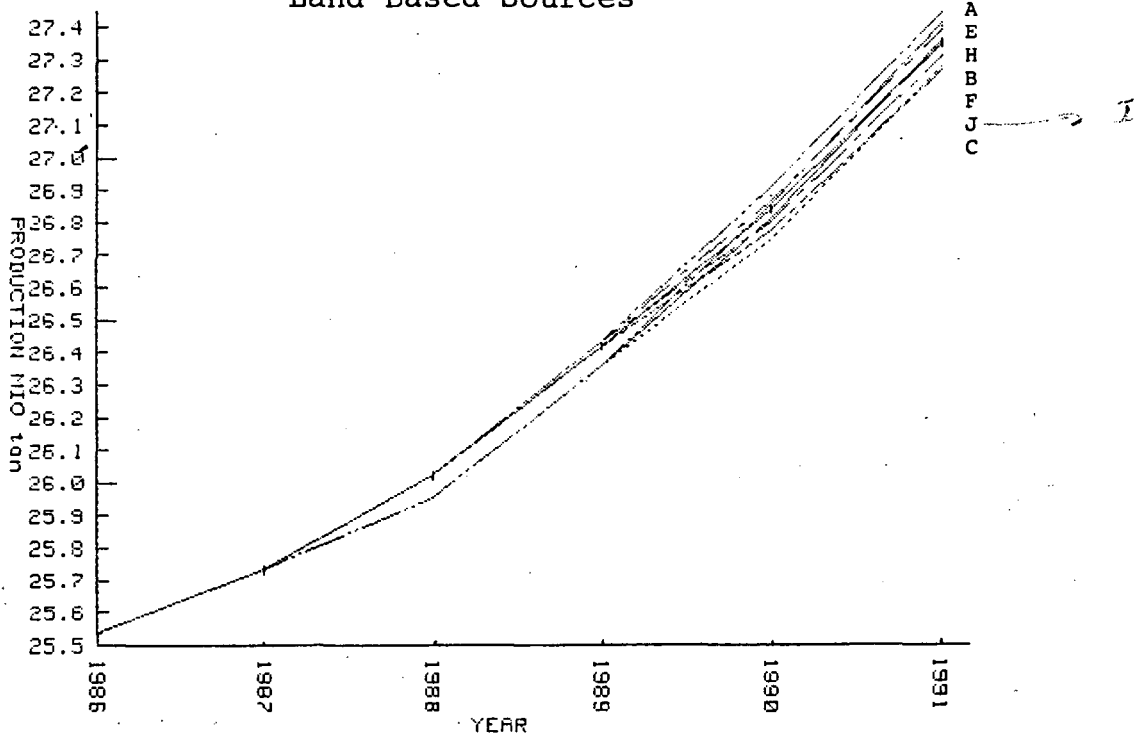
<sup>a</sup> Cif New York, deflated by the UN-Export Price Index for Manufactured Goods (1950 = 100).

Figure 3a - Forecast and Ex Ante Simulation Experiments:  
Real Price of Manganese Ore, 1981 - 1995



- A: Base case
- B: Low seabed mining
- C: High seabed mining
- D: Change in GSA stockpile and no seabed mining
- E: Change in GSA stockpile and low seabed mining
- F: Change in GSA stockpile and high seabed mining
- G: No price trend and no seabed mining
- H: No price trend and low seabed mining
- I: No price trend and high seabed mining

Figure 3b - Forecast and Ex Ante Simulation Experiments:  
Production and Imports of Manganese Ore from  
Land-Based Sources



Notes: See Figure 3a.

Finally, the impact of a situation with no price trend from 1987 to 1995 on price, imports and production from land-based sources will be considered here. From Table 10 it becomes evident that the lack of a price trend from 1987 on induces the market forces to react much more sensitively. The growth rate assumed for the activity variables in the second half of the 1980's brings about a rapid recovery of the manganese price which climbs from 39.3 US-Dollars/ton in 1988 to 63.9 in 1995, with no seabed mining. Also, in the event of seabed mining, the upward trend cannot be reversed, not even in the high production scenario. So if the downward trend in the price of manganese ore is removed a truly competitive dynamic market comes into action. Production will, of course, go up from 26 million tons in 1988 to 30 million tons in 1995, if no seabed mining takes place. In the high seabed nodule scenario world production will only be 155 thousand tons higher than in the base case by the end of the period. Hence, the sensitivity of the market to supply shocks like seabed mining is lowered and, at the same time, the impact of the activity variables on the market is enhanced<sup>1</sup>.

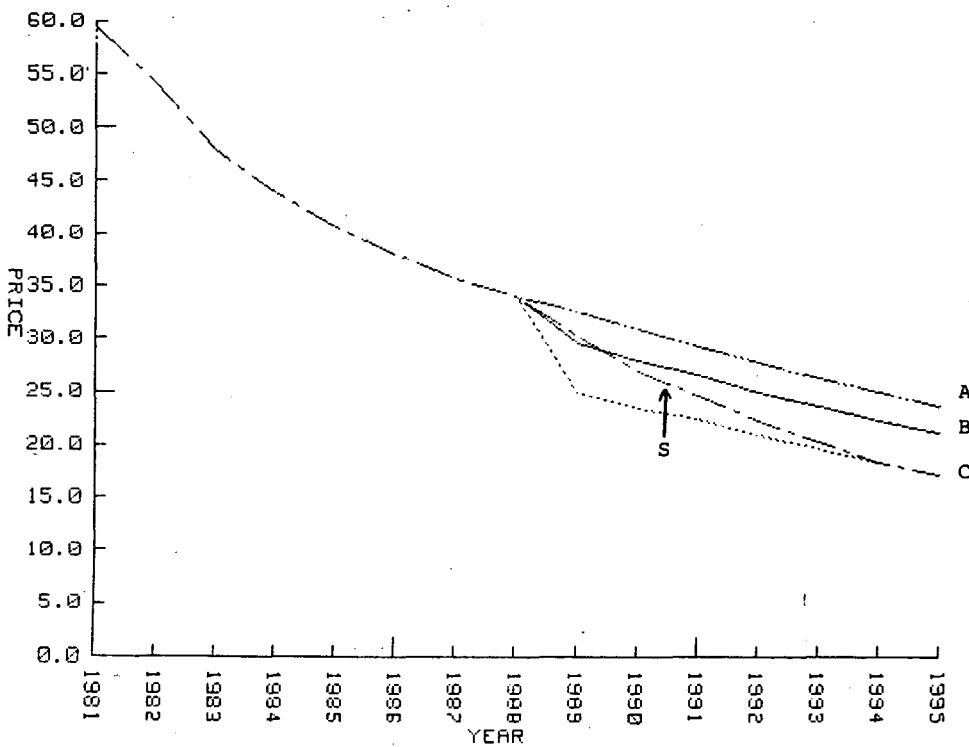
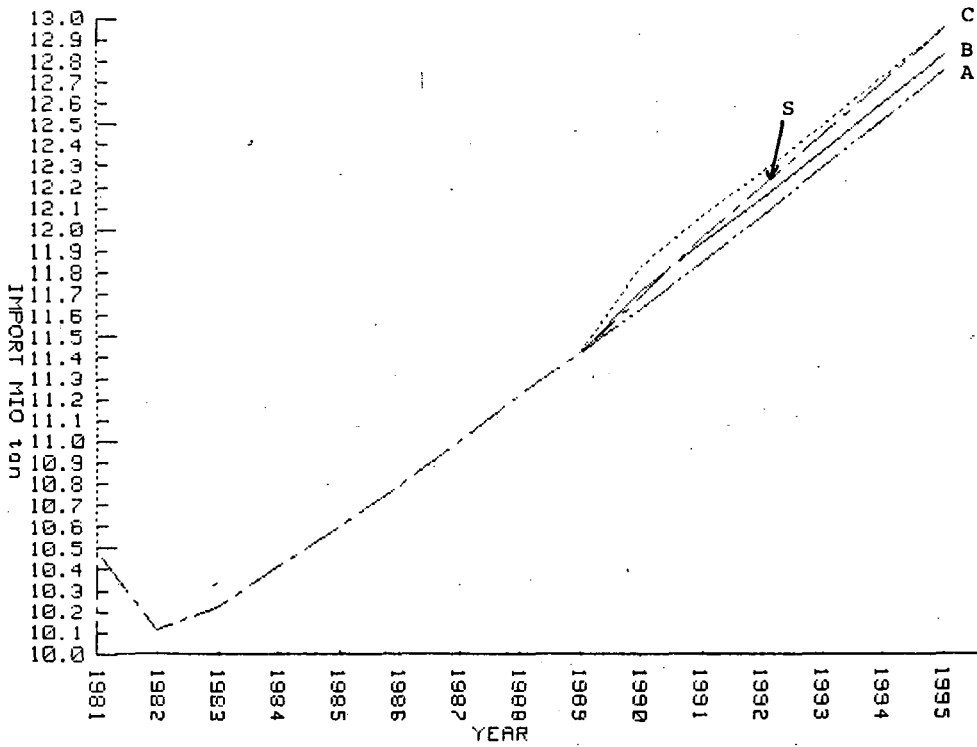
Taking, finally, a glance at the import side of the market (Table 9) reveals effects symmetric to those observed for the production side, due mainly to similar short- and long-run elasticities. The highest import level is associated with the case that lowers the price most, namely, the highest manganese production from seabed mining. Similarly, the highest price, corresponding to the no-trend assumption for the manganese price yields the lowest imports (Figure 3b).

In sum, a no-trend assumption for the price of manganese ore works as the best natural hedge against supply shocks of the kind implied by the starting up of seabed mining. The inclusion of a price trend, in contrast, depresses price and production. Finally, a moderate depletion policy by the USGSA could help to stabilize the market for manganese ore.

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<sup>1</sup> A preliminary forecast of the manganese market up to 1989 under alternative scenarios (including deepsea mining) and featuring the no-price-trend hypothesis was presented in Foders and Kim (1982).

Figure 4 - Impact of Stepwise Expansion of Manganese Output from Seabed Nodules on Imports and Price of Manganese Ore, 1981 - 1995



S: Stepwise expansion of manganese output from seabed nodules (Tables 9, 10)

A: Base case

B: Low seabed mining

C: High seabed mining

## V. Summary of Findings

In this paper a dynamic commodity model for manganese has been presented. After its validation the model has been used in ex ante simulation experiments to analyze the impacts of supply shocks and other exogenous factors on production, imports and the price of manganese ore.

Our model represents, in contrast with the pioneer econometric model built for UNCTAD, a competitive market where the price generally determines supply and demand. Supply (as production) equations were estimated for South Africa, Australia, the Soviet Union, and for 'others'. On the other hand, demand (as imports) was estimated for Japan, Western Europe, the US, and 'others'. The model also includes an equation determining the real price of manganese ore, featuring independent variables representing the GSA stockpile level, changes in commercial stocks (as market pressure), and the price of the most important complement of manganese in steel making, iron ore. Three identities close the model.

Our commodity model belongs to the family of recursive models which embody the market's adjustment process in the form of a unilateral flow of causation over time. The recursive nature of the present multi-equation model has been proved by showing that the matrix of structural-form coefficients on current endogenous variables is triangular, and that its variance-covariance matrix of stochastic disturbances is diagonal.

Validation of the model has been carried out in terms of dynamic historical simulation (including an ex post forecast) and deterministic stability analysis. In the historical simulation, average root-mean-square-percentage-errors amount to 5 percent on the supply side, 9 percent on the demand side and 13 percent for the price. The analysis of the latent roots pertaining to a linearization of our model shows that ten out of twelve eigenvalues

satisfy standard stability criteria. Only two complex latent roots with a modulus greater than unity imply a certain degree of unstable oscillatory behaviour in the long run. However, we conclude that our model is stable in the short and medium terms.

Then, the model is simulated to obtain a forecast of supply, demand and prices from 1982 to 1995 as a base case to be compared with various additional simulation runs under alternative scenarios. The aim of these simulation experiments is to quantitatively assess to impact of ocean bed mining of manganese nodules on the manganese market. In the base simulation actual and expected developments in the world steel industry result in a very slow demand growth during the period under consideration, extending the historical downward trend in price into the 1990's. The startup of seabed mining from 1988 onwards depresses the price even more. Obviously, better prospects for the activity in the steel industry could reverse such a trend. To test for the capacity of the manganese market to adjust to such a hypothetical situation the trend was omitted in the price equation. Our computations show that if the trend variable is dropped the market is freed from the said downward trend in price, being able to absorb low and high supply shocks from seabed mining in terms of competitive adjustment. Finally, a moderate stock depletion policy by the GSA would help to stabilize the market.

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APPENDIX I

Recursive Properties of the Model

For an equation system to be recursive two conditions must be satisfied:

- the matrix of structural-form coefficients on the current endogenous variables is triangular
- the matrix of variances and covariances of the stochastic disturbance terms is diagonal.

The first condition refers to the said unilateral flow of causation from lower-numbered to higher-numbered equations. The second condition insures that the contemporaneous stochastic disturbance terms are uncorrelated across the different equations. It remains to be seen now if our model meets the required restrictions which - if satisfied - impart very generous identification and estimation properties to it. The next sections deal with these matters.

1. Analysis of Structural Form Coefficients on Current Endogenous Variables

The structural form of our model can be written as

$$(A1) \quad Y(t) = A \cdot Y(t) + B \cdot Y(t-1) + D \cdot X + U(t)$$

or

$$(A2) \quad (I - A) \cdot Y(t) = B \cdot Y(t-1) + D \cdot X + U(t)$$

where  $Y(t)$  is a  $k \times n$  matrix of  $k$  current endogenous variables,  $n$  being the number of observations,  $Y(t-1)$  a  $k \times n$  matrix of  $k$  lagged endogenous variables,  $X$  a  $m \times n$  matrix of  $m$  exogenous variables,  $U(t)$  a  $k \times n$  matrix of stochastic disturbance terms,  $(I - A)$  a  $k \times k$  matrix of (normalized) coefficients on the current endogenous variables,  $B$  a  $k \times k$  matrix of coefficients on the lagged endogenous variables, and  $D$  a  $k \times m$  matrix of coefficients on the exogenous variables<sup>1</sup>.

<sup>1</sup> Intercepts are included in matrix  $D$ . To account for this, one of the components of matrix  $X$  is a unit vector.

According to the first of the above stated conditions to be met by a truly recursive model the matrix  $(I - A)$  in equation (A2) has to be triangular. This is clearly the case, as can be inferred from Table A1. The resulting lower triangular matrix was obtained reordering rows and columns, yet without interchanging them, so that all off-diagonal non-zero entries lie only on the lower side of the principal diagonal. This triangular matrix only shows entries on the diagonal which are positive and equal to one, and entries under the diagonal which are negative but also equal to one. Since the latter entries are concentrated in the last three rows, it becomes obvious that the first nine equations are completely unrelated. The tenth equation, an identity corresponding to the endogenous variable MPTO (total world production of manganese ore), includes unit coefficients for the production variables MPAU (production of Australia), MPSA (production of South Africa), MPSO (production of the Soviet Union), and MPOT (production in other countries) which are independently determined in lower-numbered equations. Similarly, MMTO (total imports) the eleventh equation (also an identity), includes single country import variables from lower-numbered equations. Finally, the last equation is a non-linear identity where MFTO (our proxy for changes in commercial stocks) is defined as the ratio of total imports to total production, thus using endogenous variables determined in the tenth and eleventh equations<sup>1</sup>.

## 2. Analysis of the Covariance Matrix of Stochastic Disturbances

In this section we shall turn to the second restriction imposed on the parameters of truly recursive systems, namely a diagonal matrix of variances and covariances of stochastic disturbances. Again starting from the structural form of our simulation model, written as

$$(A3) \quad (I - A) \cdot Y(t) - B \cdot Y(t-1) - D \cdot X = U(t)$$

<sup>1</sup> For simplicity, though, this identity was linearized for triangulation. Instead of  $MFTO = MMTO / MPTO$  the specification  $MFTO = MMTO + MPTO + M$  was used, where  $M$  is an exogenous variable determined by historical simulation results.

Table A1 - Triangularized Matrix of Structural-Form Coefficients on Current Endogenous Variables

	I	MPAU	MPSA	MPSO	MPOT	MMEU	MMJA	MMUS	MMOT	PUS	MPTO	MMTO	MFTO
MPAU	I	X	0	0	0	0	0	0	0	0	0	0	0
MPSA	I	0	X	0	0	0	0	0	0	0	0	0	0
MPSO	I	0	0	X	0	0	0	0	0	0	0	0	0
MPOT	I	0	0	0	X	0	0	0	0	0	0	0	0
MMEU	I	0	0	0	0	X	0	0	0	0	0	0	0
MMJA	I	0	0	0	0	0	X	0	0	0	0	0	0
MMUS	I	0	0	0	0	0	0	X	0	0	0	0	0
MMOT	I	0	0	0	0	0	0	0	X	0	0	0	0
PUS	I	0	0	0	0	0	0	0	0	X	0	0	0
MPTO	I	X	X	X	X	0	0	0	0	0	X	0	0
MMTO	I	0	0	0	0	X	X	X	X	0	0	X	0
MFTO	I	0	0	0	0	0	0	0	0	0	X	X	X

it is typically assumed in the general case that the stochastic disturbance column vectors  $u_j$  in the  $k \times n$  matrix  $U(t)$  each have a zero mean and that the corresponding covariance matrices

$$\begin{aligned} \text{cov}(u_j) &= E(u_j \cdot u_j') = \Sigma = \\ &\begin{matrix} \sigma_{11} & \sigma_{12} & \cdots & \sigma_{1k} \\ \sigma_{21} & \sigma_{22} & \cdots & \sigma_{2k} \\ & \cdot & & \\ & \cdot & & \\ & \cdot & & \\ & \sigma_{k1} & \sigma_{k2} & \cdots & \sigma_{kk} \end{matrix} \\ &= \quad \cdot \quad \quad \quad , \text{ for } j = 1, 2, \dots, n \end{aligned}$$

are the same at each observation<sup>1</sup>. Also, the elements of the vectors  $u_j$  are supposed to be uncorrelated over the sample. Furthermore, while the stochastic disturbances may be uncorrelated over the sample they can still be correlated across equations. The latter is the characteristic feature of truly interdependent equation systems, and shows itself in terms of non-vanishing covariances (the off-diagonal elements in matrix  $\Sigma$ ). Now, in the case of a non-interdependent recursive equation system this last assumption does not hold, i. e. the covariances between the stochastic disturbance terms in any two different equations vanish. Table (A2) presents the covariance matrix of our model for the world manganese market. Since the statistical significance of these sample covariances cannot be assessed, we proceeded to calculate product-moment correlation coefficients for every pair of stochastic disturbance vectors. Of course, considering that the matrix  $\Sigma$  is symmetric positive-definite only correlations between the disturbance vector from any equation and the ones of higher-numbered equations have to be calculated. Doing this yields a triangular correlation matrix as shown in Table (A3).

<sup>1</sup>  $\Sigma$  is a  $k \times k$  matrix. However, since identities are free of own stochastic disturbances this matrix has the dimension  $k-d \times k-d$ ,  $d$  being the number of identities in the model.

Table A2 - Variance-Covariance Matrix of Stochastic Disturbance Terms

	MPAU	MPSA	MPSO	MPOT	MMEU	MMJA	MMUS	MMOT	PUS
MPAU	37727.816	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MPSA	9420.163	67442.605	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MPSO	-525.946	26407.739	82020.834	0.000	0.000	0.000	0.000	0.000	0.000
MPOT	-61860.574	-64399.589	14933.211	471354.741	0.000	0.000	0.000	0.000	0.000
MMEU	33145.650	55016.988	15515.628	-25269.174	153365.691	0.000	0.000	0.000	0.000
MMJA	-2283.899	3232.094	-5748.518	38409.369	24633.564	43010.352	0.000	0.000	0.000
MMUS	-5271.499	25152.112	48089.015	76136.145	35118.726	12798.931	121188.193	0.000	0.000
MMOT	6949.676	15629.520	12445.672	-26042.545	18994.334	-1693.012	20693.230	33703.112	0.000
PUS	325.597	-1106.526	-576.613	1148.123	130.932	100.182	-110.506	-203.950	47.663

Table A3 - Product Moment Correlation Coefficients of Stochastic Disturbance Terms

	MPAU	MPSA	MPSD	MPDT	MMEU	MMJA	MMUS	MMOT	PUS
MPAU	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
MPSA	0.1867	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
MPSD	-0.0095	0.3551	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
MPDT	-0.4639*	-0.3612	0.0759	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000
MMEU	0.4329*	0.5375*	0.1374	-0.0934	1.0000	0.0000	0.0000	0.0000	0.0000
MMJA	-0.0567	0.0600	-0.0968	0.2698	0.3013	1.0000	0.0000	0.0000	0.0000
MMUS	-0.0780	0.2782	0.4823*	0.3186	0.2559	0.1773	1.0000	0.0000	0.0000
MMOT	0.1949	0.0278	0.2367	-0.2066	0.2625	-0.0445	0.3238	1.0000	0.0000
PUS	0.2428	-0.6172**	-0.2916	0.2422	0.0481	0.0700	-0.0460	-0.1609	1.0000

\* - SIGNIFICANT AT THE 5% LEVEL  
 \*\* - SIGNIFICANT AT THE 1% LEVEL

Of the 36 correlation coefficients in Table (A3) only one (MPSA with PUS) turns out to be significant at the one percent level. At the five percent significance level five coefficients have to be considered: MPSO with MMUS, MPSA with PUS, MPAU with MMEU, MPSA with MMEU and MPAU with MPOT. Only one of these, namely MPAU (production of Australia) with MPOT (production of other countries) reflects the problem known as "seemingly unrelated equations", so common in systems of demand and supply equations when one or both sides of the market are split into single country equations. In spite of this, our sample covariance matrix can be said to approximate quite well the second condition to be met by recursive models, i. e. a diagonal covariance matrix of stochastic disturbances.

### 3. Identification and Estimation of Recursive Models

Recursive models are often called the most simple of equation systems. The reason for this is not only the intuitively appealing unilateral causal flow structure but also the very simple identification and estimation properties shown by recursive models.

An equation system is said to be identified if it is possible to infer the non-zero structural-form coefficients from the reduced-form coefficients. In the case of the general multi-equation model reduced-form parameters are not sufficient to estimate the structural-form parameters, so that not only a posteriori information about the structural-form, like the reduced-form estimates, but also a priori information is needed. The latter consists in imposing some restrictions on the structural-parameters. One way of doing this is through zero restrictions either on the matrix of structural-form coefficients on the current endogenous variables or on the structural-form covariance matrix, or on both matrices.

As has been said above recursive systems typically show a triangular matrix of structural-form coefficients on current endogenous variables and a diagonal structural-form covariance matrix. This means that recursive systems are by definition subject to zero restrictions. Fisher (1976) has proven, that these special features of recursive models make them satisfy both necessary and sufficient criteria for identifiability, i. e., the order and rank conditions. The triangular coefficient matrix identifies a given equation with respect to higher-numbered equations; the diagonal covariance matrix is used to identify those higher-numbered equations.

The estimation of exactly identified models bearing a recursive structure does not call for sophisticated estimation methods. It can be shown (Intrilligator, 1978, pp. 415 and 416) that in the recursive case the OLS estimators are also Full-information maximum-likelihood (FIML) estimators. Hence OLS estimates are consistent and asymptotically efficient. However, the presence of serial correlation yields biased OLS estimates. In our case each of the first nine uncorrelated equations can be estimated independently. The three remaining equations are identities that do not require estimation. From the first nine equations only two have serially correlated stochastic disturbances. These equations were not removed because GLS and instrumental-variables technique estimates did not perform so well in the historical simulation.

Recursive models have been defended by Wold (1954; Strotz, Wold, 1960) on the grounds that besides having desirable identification and estimation properties they approximate economic reality much better than interdependent models. While it is true that the latter models, interpreted in the sense of general equilibrium models of the Cournot-Walras type, do not describe the actual process of reaching equilibrium, thereby obscuring the underlying relationships of cause and effect, the above thesis does not seem to hold in a general fashion. A general equilibrium model is expected to take into account the interdependence between the different markets in an economy, assuming that the agents acting



on each of these markets follow a certain causal chain. This assumption is never made explicit in interdependent models, because emphasis is laid only on simultaneity of action. On the other hand, in some studies attention is paid only to a subset of the markets in an economy, disregarding any feedbacks from the markets which were left out of the analysis. In some cases even one market alone might be of interest if the details of the adjustment process on this market are to be studied. This market adjustment process can best be modelled in terms of a recursive model which explicitly embodies the unilateral flow of causation<sup>1</sup>. It is along these lines that our model of the manganese market should be understood.

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<sup>1</sup> Of course, sometimes it can be difficult to build a truly recursive model due to data problems. That is why many estimated models include interdependencies that can hardly be explained by economic theory.

## APPENDIX II

### Data Sources

#### a. Exogenous Variables

##### Iron Ore Price (PFO):

Iron and Steel, Mineral Commodity Profiles, Bureau of Mines, United States Department of the Interior, various issues;  
Metal Statistics, American Metal Market, Fairchild Publications, various issues.

##### US Government Stockpile (GSA):

An Econometric Model of the Manganese Ore Industry, United Nations Conference on Trade and Development, TD/B/483/Add. 1, 1974;  
Manganese, Mineral Commodity Profiles, Bureau of Mines, United States Department of the Interior, various issues.

##### Pig Iron and Ferroalloy Production of Japan (FPJA) and World (FPTO):

Statistical Summary of the Mineral Industry, the Statistical Section, Mineral Resources Division, Overseas Geological Surveys, various issues;  
The Iron and Steel Industry and Trends, A Study by the Special Committee for Iron and Steel, OECD, various issues.

#### b. Endogenous Variables

##### Manganese Ore Production of Australia (MPAU), South Africa (MPSA), Soviet Union (MPSO), and Others (MPOT), and Manganese Ore Imports of Europe (MMEU), Japan (MMJA), USA (MMUS), and Others (MMOT):

Statistical Summary of the Mineral Industry, The Statistical Section, Mineral Resources Division, Overseas Geological Surveys, various issues;  
Metal Statistics, American Metal Market, Fairchild Publications, various issues.

##### Price of Manganese Ore (P):

Manganese, Mineral Commodity Profiles, Bureau of Mines, United States Department of the Interior, various issues;  
Review of Recent Developments in the World Market for Manganese, UNCTAD, various issues;  
Metal Statistics, American Metal Market, Fairchild Publications, various issues.

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159. M. Hoffmeyer, J. Schrader, T. Zotschew, Marine antarktische Ressourcen und Antarktischforschung. November 1982, 150 S.
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162. A. Neu, Entwicklungstendenzen der Gaswirtschaft in der globalen und regionalen Energieversorgung. Dezember 1982, 77 S.
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