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Recent Developments in Commodity Modeling

A World Bank Focus

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A review of the state of the art of Bank commodity modeling for forecasting and analysis of supplies, demand, and prices.

The Bank has been on the cutting edge in the development and application of models of primary commodity markets and industries — those involving raw materials, agricultural products, and unprocessed or incompletely processed fuel and nonfuel minerals.

The Bank's International Commodity Markets Division uses these models to forecast commodity supply, demand, and prices for use in project evaluation, market and policy analysis, global economic projections, and assessments of the development prospects in developing countries.

In the 1980s, commodity market modeling became less experimental, more realistic, and more directly oriented to the kinds of commodity price forecasts needed for overall Bank efforts — for example:

- Short-, medium-, and long-term forecasts for market adjustments for cocoa and coffee.

- What-if supply forecasts for coffee under different price scenarios for coffee and fertilizer.

- Analyzing and forecasting long-term changes in multiple-commodity markets (say, for fats and oils and high protein meals or for different forms of minerals).

- Analyzing the effects of changing inventories and oil prices and the availability of synthetics on the supply and price of rubber.

- Analyzing the effect of adjusting capital shocks on perennial tree crops.

- Examining the effect of changes in inventory or inflation on commodity price movements.

Researchers have made the models more realistic by factoring in such considerations as risk (particularly for agricultural supplies); the influence of synthetic substitutes on demand for primary commodities; and the influence of noncompetitive market structures on oil prices and trade patterns.

Price and quantity forecasting has been the major focus of Bank modeling efforts, but the Bank also examines such other issues as investment policies, optimal market stabilization, and pricing strategies.

This paper is a product of the International Commodity Markets Division, International Economics Department. Copies are available free from the World Bank, 1818 H Street NW, Washington DC 20433. Please contact Aban Daruwala, room S7-040, extension 33716.

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I. INTRODUCTION

The past two decades have witnessed a literal explosion in the development and application of models of primary commodity markets and industries. This class of commodities normally encompasses raw materials, agricultural products, and fuel and nonfuel minerals in their unprocessed or only first-processed state. These models have been built for a variety of purposes such as forecasting and policy analysis and have employed a variety of methodologies. Although these models suffer the kinds of problems experienced by other economic and engineering models, they are being used increasingly by international organizations, private corporations and research and governmental institutions who analyze commodity markets and commodity development problems.

It is thus not surprising that commodity models have played a significant role in the Bank's efforts to analyze important policy issues in commodity markets and to provide commodity price forecasts. The tasks of building and applying these models have been performed by what is now the International Commodity Markets Division. The functions of this Division are basically two-fold. First, it provides market analyses and long-term price forecasts for the Bank's project evaluation activities involving primary commodities. Second, it provides country desks within the Bank with detailed short-term forecasts of commodity prices and trade for their balance of payments analyses and projections as well as their assessments of the country's creditworthiness. In addition, the various market analyses and price forecasts have played an important role in the Bank's medium and long-term global economic projections.

After the first oil price shock the Bank embarked on an exercise to assess the development prospects of developing countries. (These studies later became the World Development Reports). A major building block of the quantitative framework for these reports have been the price and quantity feedthrough effects on developing countrys' commodity exports. The first large-scale modelling exercise of this kind was the SIMLINK model, which aimed to assess the impact of the first oil price shock on the economies of developing countries.

It should be recognized that application of commodity models had existed prior to this period within the Bank. Later this work expanded not only to include a greater number of commodities but also to improve the quality of the models as well as their forecasting capabilities. Considerable effort was put into estimating commodity demand and supply equations for major consuming and producing countries. However, almost all of these models assumed one market clearing price. (This reflected the Division's practice of using essentially only one single price quotation/ projection per commodity market.) In parallel with the effort to develop econometric commodity models, there were also several attempts to building commodity models using a spatial equilibrium or programming approach. While price and quantity forecasting remained the major focus of the modelling effort, increasingly modelling also attempted to examine other issues, such as investment policies, optimal market stabilisation mechanisms, and pricing strategies.

In their day-to-day application, projections based on commodity models have been used principally as a 'benchmark' against which 'judgmental' projections could be compared. These comparisons with judgmental projections as well as with ex post simulations instigated efforts to update and revise the various models. Thus, in a way, the efforts to build commodity models have helped commodity specialists to gain a deeper understanding of commodity markets. While the models did provide the needed consistency between projections of supply, demand, trade and prices, they more importantly, sharpened the judgments of the analysts, in particular with respect to factors that have been difficult to incorporate in commodity models. Today, commodity models are being used more than ever to produce and to maintain the Bank's system of commodity price forecasting and to perform the mentioned market analyses.

This paper provides insights into international commodity modeling by providing a survey of recent developments in this modeling area and by explaining how these developments interacted with and were applied within the Bank. Following a brief introduction into basic commodity modeling purposes, a fuller description is given of the nature of the various methodologies, and of recent advances in their formulation. The Bank's employment of these methodologies in constructing and operating a variety of commodity models is then discussed. While a perspective is provided regarding historical modeling developments within the Bank, most of the review is concerned with the Bank's recent success in utilizing these models for forecasting and market analysis purposes.

II. COMMODITY MODELING DEFINED

A commodity model is a quantitative representation of a commodity market or industry; the behavioral relationships included reflect demand and supply aspects of price determination as well as other related economic, political and social phenomena.[1] Most commodity models are composed of a number of components which reflect various aspects of demand, supply and price determination. Figure 1 presents an example of these aspects and their typical interrelation in the case of a simple commodity market model.

The structure of this model can be interpreted in two ways. Temporal structures are the most common form of commodity model. Over time commodity demand and supply are likely to be in disequilibrium and this gives rise to inventory holding. The values of the demand and supply "flow" price elasticities relative to the inventory demand and supply "stock" elasticities determine the speed with which the quantity market adjusts in its movement towards equilibrium. The same demand and supply configurations can also be considered regionally or spatially. In this case market equilibrium is achieved by the resolution of differences between prices in demand and supply regions relative to transport costs between those regions. Sometimes temporal and spatial configurations are included in the same modeling approach.

There should be no doubt that the construction of commodity models is a difficult process. International commodity markets are complex organisms, often with many actors and sectors involved in commodity production,

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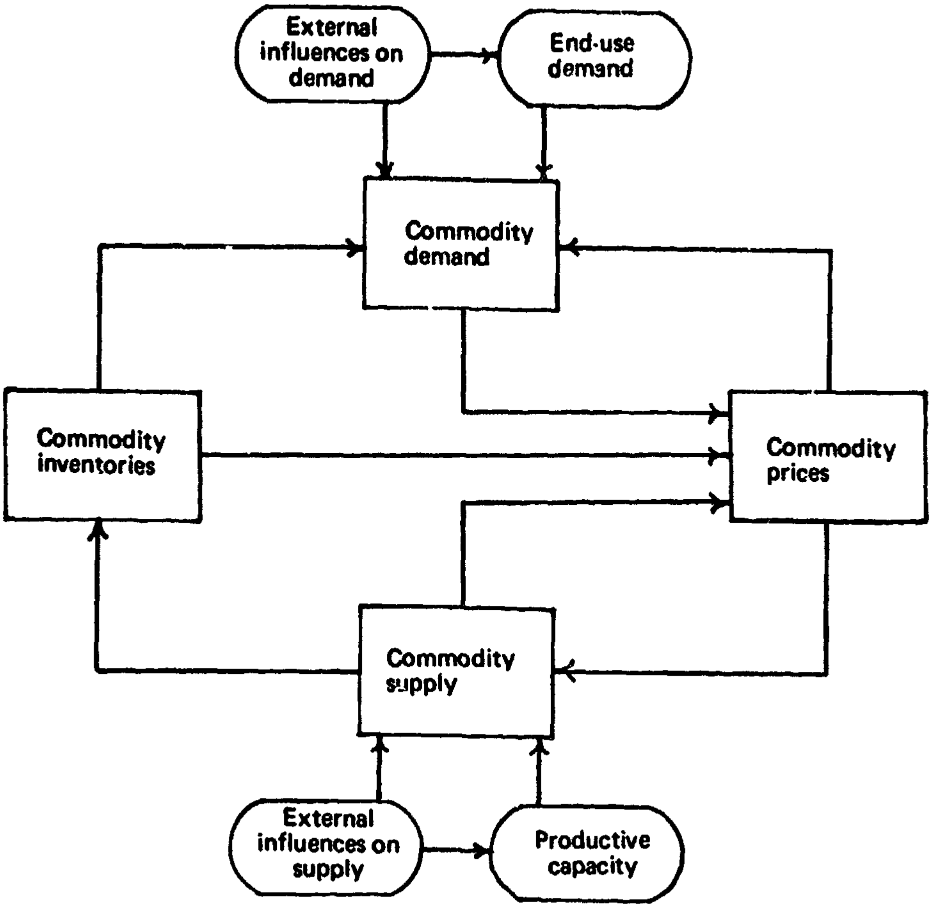
[1]This discussion and the subsequent explanation of modeling methodologies appears from W.C. Labys and P. Pollak, Commodity Models for Forecasting and Policy Analysis, Croom-Helm, London, 1984. Interested readers should also refer to W.C. Labys, Commodity Markets and Models: An International Bibliography, Gower Publishing Co., London, 1987.

Figure 1. MODEL REPRESENTATION OF A COMMODITY MARKET



Source: W. C. Labys and P. Pollak. Commodity Models for Forecasting and Policy Analysis. London: Croom-Helm Publishing Co., 1984.

consumption, inventory holding, capacity formation, trade, etc. Models often cannot duplicate this complexity and detail. Given the enormity of the task, good modeling requires simplification and abstraction to represent the essential elements of the system under examination. Of importance not only is the detailing of individual relationships concerning say consumption or prices but also the competitive nature of the overall market structure.

The approach that is taken to construct commodity models resembles that of other economic models: (1) Determination of modeling purpose(s), (2) Selection of model structure, (3) Specification of relationships, (4) Estimation of parameters, (5) Validation, and (6) Model solution or simulation. The purposes of constructing World Bank models center around short and long term forecasting and policy simulation analyses. Short-term forecasting has been concerned with commodity prices and export earnings. Uncertainty surrounds the fluctuations in these variables, because of sudden changes in industrial activity relative to commodity inventory levels. Long-term forecasting has been performed to gain knowledge about supply response and future supply availability as well as prices. Policy simulation analysis helps to answer "what if" questions about past or future commodity market responses to particular policies such as buffer stock stabilisation, or to institutional changes.

The selection of the structure of a commodity model reflects not only the formal methodology employed including model specification, estimation and simulation but also the attributes of the commodity market or a particular commodity problem to be analyzed. Examples of such attributes include the noncompetitive or cartel nature of a market, the presence of international stockpiles, or a range of tariff or nontariff trade barriers. Also relevant in this context is the empirical scope of a model. While almost all econometric commodity models are temporal, some of these also embody important spatial characteristics. The degree of disaggregation also is significant particularly with respect to commodity end-uses.

Model specification is concerned with how economic theory has been employed to transform the variables of the above structure into a set of interrelated equations. Examples include the formulation of correct lag structures in perennial tree crop or mineral resource supply equations, the production response of farmers to risk, or the measurement of synthetic substitution effects. Model estimation requires computing the parameters of the embodied regression equations with techniques that assure their unbiasedness, efficiency and sufficiency.

Model validation requires that certain tests be performed with a model so that model users can have confidence in the ability of the model to perform reasonably well. The validation process normally embodies a series of tests, most of which are statistical in nature. For example, one can test the significance of model parameters, the accuracy between actual or forecast values of particular variables, or the ability of a model to predict "turning-points" correctly. In the case of simulation analysis, the accuracy of the behaviorial response is often evaluated in terms of the realism of this response, when subjected to sensitivity analysis.

Model simulation refers to the organization of the underlying computer software for solving a commodity model over successive periods of time or over regions. Today, since models are larger or integrated and many variables have to be manipulated, more complex simulation systems are required. Simulation programs also often have special features which assist in model validation or in policy sensitivity analysis such as those embodying Monte-Carlo techniques.

III. RANGE OF MODELING METHODOLOGIES

No single model can meet all modeling purposes. This sometimes requires that entirely different kinds of quantitative methodologies be employed to meet these different purposes. Some examples of the kinds of modeling analysis that can be performed include the following:

1. Market forecasting analysis concerns the short, medium or long run forecasting of commodity quantities and prices. Sometimes this forecasting is of a conditional or "what-if" nature.

2. Policy simulation analysis considers how markets or industries react to changes in national or international policies, also on a "what-if" basis.

3. Market stabilization analysis involves finding those control mechanisms or forms of market organization which lead to more stable price or equilibrium positions.

4. Market planning analysis relates to the projecting of long run outcomes, depending on the policy problems or market strategies of interest. Commodity investment analysis is of this type.

5. Supply restriction analysis requires that a probabilistic theory describing the possibilities of sudden supply or import disruptions be integrated with domestic market analysis.

6. Agricultural process analysis explains the influence that farm level decisions, technology, aggregate demand and prices have on agricultural output.

7. Industrial process analysis describes the relationship that exists between national activities, technical transformation processes within industries, and commodity input demands.

8. Analysis of spatial flows requires the application of spatial economic theory at the commodity level so that the relations of demand, supply and transportation costs to commodity trade flows can be determined.

9. Economic growth analysis can solve problems of planning for growth, where commodity exports represent the 'engine' or primary sector of country growth.

The task of the commodity modeler is to perform any of the above analyses to meet the needs of the model user. This is a complex task and it is difficult to summarize it briefly. At the risk of oversimplification, Table 1 has been constructed to suggest the kinds of modeling methodologies that are consequently employed. The manner in which the methodologies are applied is also featured in the form of the modeling process: What is the purpose of the methodology? What quantitative methodology is used? What economic behavior is specified? And what are some examples of commodity applications? Let us briefly examine each of these methodologies reflecting also on recent "state of the art" developments, so as to assess model applicability and usefulness.

<u>Market Models</u>

Market models, usually based on econometric methods, stem from a tradition beginning with the first demand and supply equations estimated in the 1940s. As implied above, a market model is concerned with the determination of prices and with the behavior of participants in the market. Focusing on the price mechanism which serves to clear the market, the standard commodity market model (SCM) consists of four relationships, although much more complex structures are used in practice.

$$D_t = d(P_t, P^c, A_t, T_t)$$
$$Q_t = q(P_{t-\theta}, N_t, Z_t)$$
$$P_t = p(I_t/D_t)$$
$$I_t = I_{t-1} + Q_t - D_t$$

Commodity demand is explained as being dependent on prices P, economic activity A, prices of one or more substitute commodities P^c, and possible technical influences such as the growth of synthetic substitutes T. Other possible influencing factors and the customary stochastic disturbance term have been omitted for simplification; the subscript t refers to time. Accordingly commodity supply Q depends on prices as well as underlying

Table 1

COMMODITY MODELING METHODOLOGIES AND THE MODELING PROCESS

Methodologies	What is the purpose of the methodology?	What quantitative method is used?	What economic behavior is specified?	Examples of Commodity Applications
Market Models	Demand, supply, inventories interact to produce an equilibrium price in competitive or noncompetitive markets	Dynamic micro econometric system composed of difference or differential equations	Interaction between decision makers in reaching market equilibrium based on demand, supply inventories, prices, trade, etc.	Cocoa Coffee Jute Sugar Tin
Spatial Equilibrium and Programming Models Linear and Quadratic Programming	Spatial flows of demand and supply and equilibrium conditions assigned optimally in equilibrium depending on configuration of transportation network	Activity analysis of a spatial and/or temporal form. Degree of complexity depends on endogeneity and method of incorporating demand and supply functions	Interaction between decision makers in allocating shipments (exports) and consumption (imports) optimized through maximizing sectoral revenues or minimizing sectoral costs	Iron and Steel Lead and Zinc
Mixed Integer Programming	Spatial and temporal equilibrium embodying production-process, transportation, and project investment components	Activity analysis involving spatial and temporal optimization but also including integer (0,1) variables to represent capacity additions	Interaction between decision makers in finding minimum discounted costs of meeting specific market requirements, i.e., project selection	Aluminum Copper Fertilizers Iron Ore
Optimization Models	Supply and demand analyzed in relation to optimal resource exhaustion over time and cartel behaviour	Dynamic micro econometric system featuring formal cartel-fringe models such as that of monopoly, Stackelberg or Nash-Cournot	Interaction between decision makers in optimizing resource allocation and prices over time in noncompetitive markets involving bargaining activity	Aluminum Copper Crude Oil
Systems Dynamics Models	Demand, supply, inventories interact to produce an equilibrium price emphasizing role of amplifications and feedback delays	Dynamic micro econometric differential equation system which features lagged feedback relations and variables in rates of change	Interaction between decision makers in adjusting rate of production to maintain a desired level of inventory in relationship to rate of consumption	Aluminum Broilers Cattle Copper Hogs Orange Juice
Input-Output Models	System regarded as process that converts raw materials into intermediate and final products via intermediate processes	Input-output model combined with macro economic framework or disaggregated raw materials balance framework	Interaction between non-fuel and fuel commodities and macro markets in reaching materials and energy balance including supply-demand determination	Minerals Energy Agriculture

Source: W. C. Labys, and P. K. Pollak, Commodit [illegible] lodels fo [illegible] Pub! [illegible] pp.

productivity factors such as agronomic or geological influences N, and possible policy variables Z. A lagged price variable is included since the supply process often involves a gestation period θ based on past expectations concerning profits and prices.

The model is closed using an identity which equates inventories with lagged inventories plus supply minus demand. Where the price equation is inverted to represent inventory demand, the identity can be recognized as the equivalent supply of inventories equation. The modeling of commodity markets entails integrating all of the above components into the overall market or industry structure. But before reaching the complete market or model structure, the modeler must often deal with a number of conceptual problems.

To begin with, the time span of the model of interest must be decided. Is the market behavior to be analyzed or forecast of a short, medium or long term nature? Depending on the term, different temporal aspects of the specification must be considered. There is also the need to re-examine conventional notions about adjustment mechanisms which move commodity markets towards equilibrium. Price may not be the result of competitive adjustments; consequently market structures reflective of monopolistic competition must be investigated. This appears to be more frequent in mineral markets where production sometimes is not competitively determined and supply behavior must be based on cost relationships. Some markets may also never attain equilibrium in the sense that supply always equals demand at different points in time; thus the disequilibrium characteristics of the market must be modeled. Finally, the market represents more than an economic mechanism. Other information needs to be introduced, which relates to the institutions and the organization of the market, the behavioral patterns of industries and firms, and the government policies affecting the market.

Today commodity market models are employed widely in the preparation of commodity quantity and price forecasting. They are increasingly being combined with other methodologies to produce more sophisticated model structures. Previous applications of this approach have been described in Adams and Behrman (1978) and Labys and Pollak (1985). One interesting development has been the design by Adams and Behrman (1976) of "mini" market models which can be operated independently or as satellites to larger national or international modeling systems. More recently Verleger (1982) has used a market model to explain world oil prices during conditions when the market shifts between conditions of stable and of restricted supply. And Ghosh et al (1987) have applied optimal control theory to a copper model to determine conditions suitable for market stabilization and optimization.

Spatial Equilibrium and Programming Models

An alternative approach to commodity modeling concerns spatial or interregional efficiency in commodity production, distribution and utilization. Because the determination of interregional flows is best accomplishing using programming methods, this kind of model formulation also lends itself to the explanation of engineering process or the stage-of-process between different levels of commodity transformation, e.g., metal ore mining - smelting - refining - fabrication. There is considerable variety in the kinds of programming methods that can be utilized in building such models. However, those that are most frequently used include linear, quadratic, integer, and more recently linear complementarity programming, e.g., see Takayama and Labys (1985).

The most elementary form of spatial and temporal price and allocation model (STPA) begins with a set of equations describing demand D_i in region i and supply S_j in region j.

$$D_i = b_{oi} - b_{1i}P_i$$

$$S_j = b_{oj} - b_{1j}P_j$$

where P_i = commodity demand price in region i and P_j = commodity supply price in region j. Because the typical formulation of this model expresses these equations in their inverse form, the above equations are often written as

$$P_i = a_{1i} + a_{2i}D_i \qquad \text{for all } i$$

$$P_j = a_{3j} - a_{4j}S_j \qquad \text{for all } j$$

where a_1, a_2, a_3, a_4 > 0 over all observations.

The constraints imposed on the supply and demand relations reflect the market requirements that regional consumption cannot exceed the total shipment to a region and that the total shipments for a region cannot exceed the total quantity available for shipment.

$$D_i \leqq \sum_{j}^{n} Q_{ij} \qquad \text{for all } i$$

$$S_j \geqq \sum_{j}^{n} Q_{ij} \qquad \text{for all } j$$

The most simple objective function necessary to complete the model would typically minimize the costs of transporting the commodity between regions

$$\text{Minimize } L = \sum_{i}^{n} \sum_{j}^{n} T_{ij}Q_{ij}$$

In addition to the above market requirements, the basic STPA can be expanded by including various product levels and stages-of-process present in the commodity-based industries. For example, the following capacity constraint describes on the left the capacity used on productive unit m in processes p with process level Z at region i. The inequality constraint on the right reflects the capacity K of productive unit m at i. And b is a coefficient describing the degree of capacity utilization

$$\sum_{i,p} b_{m,p} \cdot Z^{m}_{p,i} < K^{m}_{i,m}$$

Other equations which can be added to the model include material balance at various production centers, maximum capacity expansion, limits to economies of scale, capital charges and operating costs for productive facilities, and tariff costs. These spatial and processing characteristics can also be analyzed dynamically over time. More complex objective functions might also consider the total benefits to commodity producers and commodity consumers within the system. In this case the models would maximize an objective function formulated in terms of net social payoff, i.e., a quasi-welfare function theorized by Samuelson (1952). This approach has received considerable application in a variety of spatial and programming formulations for a large number of commodities. More than a decade ago Judge and Takayama (1976) reported commodity applications ranging from development planning, industry location, and interregional and international trade. A more recent update of this modeling activity can be found in Labys, Takayama and Uri (1988). In that study, commodity applications are reported for coal, natural gas, aluminum, bauxite, electricity, food commodities, corn and wheat.

The multiperiod linear Mixed Integer Programing (MIP) model represents an alternative methodology for describing optimization over time. While it represents an application of linear programming over time, it also introduces an integer characteristic which accomodates combinations of 0-1 variables, reflecting the non-existence or existence of a production facility. The background to MIP stems from attempts to cope simultaneously with a number of commodity-oriented analyses, including shipping and transportation, industrial process, and project selection.

Formulating such a model begins with a transport component which resembles the spatial equilibrium transportation model given above. A process capicity component such as that just described is necessary in order to model commodity industries, for example, such as minerals or energy where a firm can produce one or more products from a primary commodity, or where a firm can produce a single product by more than one process. As an example of the first case, copper can be semi-manufactured in the form of wire, tubes and rods, or sheet strip and plate. In the second case, coal, natural gas, or petroleum can be used to generate electric power. Finally, the project selection component can be introduced by incorporating investment to augment capacity as well as economies of scale and exports.

A model that embodies these components and is operated intertemporally attempts to find the minimum discounted cost of meeting specified market requirements over the period covered by the model. This search involves, for example, the selection of activity levels for variables such as the following: (1) increments to capacity, (2) shipments from plants to markets and among plants, (3) imports and exports, and (4) domestic purchases of raw materials, miscellaneous material inputs, and labor.

Applications of this model stem from early work by Kendrick (1967) regarding the process industries. Later work has dealt with the analysis of commodity investments. For example, Dammert and Palaniappan (1985) have applied it to analyze project design in the copper industry employing a global model which includes mining, processing and fabrication. This approach has also proven appropriate for energy market analysis, including models by Langston (1983) regarding the Gulf Coast refining complex, by

Kwang-Ha (1981) concerning the Korean electric power industry, and by Jung Suh (1982) describing the Korean petrochemical industry.

Hybrid Programing Models are not a specific model type but rather various approaches for combining different model methodologies in a single framework or for constructing large-scale multi-commodity models. In particular, as the modeling process has become more sophisticated, analysts have begun to borrow skills from one another, so that the methodologies which have emerged are more difficult to classify. A glance at several recent model anthologies such as Lev (1983), Lev et al. (1984) and Quirk et al. (1982) confirms the extent to which such integration has become widespread. This phenomenon has arisen not only because of the need to integrate economic and engineering considerations, but also because of the interrelationships that exist between the commodity sector and the maroeconomic performance of national economies. For example, it is not uncommon for the demand side of an energy model to be constructed econometrically, while the supply side might be principally engineering in character. In such cases the output of several different models might be needed to provide a comprehensive analysis of a particular energy problem.

The most comprehensive effort to develop a methodology for constructing hybrid models is the "combined" energy model approach of Hogan and Weyant (1983). A theoretical as well as a computational method is employed to reach equilibrium solutions with a combined set of models. Each set of the processes or submodels are placed within an optimization framework with the inputs of each process being the outputs of others. All processes are operated simultaneously to achieve the greatest value of some objective function. The framework is organized in a way that promotes a consistent theory, natural data organization, modular design, decentralized implementation, and efficient computation. The actual model or system solution takes place using an iterative method that moves through the network of process models, solving and resolving the optimality conditions for each of the component models, while checking and updating the values of the variables in the connecting links.

While such models can analyze commodity-economy interactions in a domestic context, they also can be extended to the international level. The most well known example of such a combined model is the Project LINK system designed by Kline which attempts to evaluate trade and payments adjustments at the global level, e.g., see Waelbroek (1976). Economies of individual countries constitute the submodels and overall trade equilibrium iterations enable the prediction of changes in commodity trade patterns and in economic growth based on changes in world economic conditions. An international trade model which attempts to link commodity models with macroeconomic models of individual countries is the mentioned SIMLINK model associated with Hicks (1975). Constructed within the Bank, this model proved effective in explaining developing country export responses to world economic conditions.

Optimization Models

The major events surrounding the evolution of oil markets since 1973 have accelerated the development of optimization models. In particular, economists as well as modelers began to consider the importance of noncompetitive market structures and institutions in modeling commodity resource markets. Thus, resource optimization models were developed as a class separate from spatial equilibrium and programing optimization models. The roots of this development can be seen in the early work on the optimal depletion of exhaustible resources and on oligopolistic market behavior and bargaining processes. More recently the polar cases of perfect competition and pure monoply, as well as the continuum of intermediate market structures, have been modeled within a common framework by using a dynamic analog of the Cournot equilibrium concept. This approach assumes duopoly market behavior in the form of a non-uniform cartel, but changes the behavioral pattern of the fringe from that of followers to that of bargainers.

Applications of this approach to the world petroleum market have followed several forms of noncompetitive market behavior ranging from monopolistic to duopolistic including Stackelberg and Nash-Cournot behavior. Some of this research has involved modeling non-OPEC as well as OPEC supply relationships, e.g. see Hnyilicza and Pindyck (1976), Farzin (1986) and Marquez (1984). Modeling the oil market as a monopolist or cartel and a competitive fringe can be seen in the work of Pindyck (1978) and Cremer and Weitzman (1976). The Stackelberg model depends on one group acting as an oil price-setter and quantity follower; a second group represents an oil price-taker and quantity setter. The first group sets its prices to maximize profits, while the second groups sets its quantities to maximize profits. The operation of such a relationship to determine the optimal price for OPEC to follow in the long run was achieved by Gilbert (1978). When considering Nash-Cournot behavior, related models have been constructed to explain oil market behavior by Salant, et al. (1981) and to describe world coal market behavior by Kolstad et al. (1983).

System Dynamics Models.

This class of models utilizes behavioral relationships similar to econometric models. However, they emphasize the attributes of commodity systems that lend themselves to engineering or systems analysis:

amplification and time delays, feedback and control and stability and damping. Regarding model origins, Meadows (1970) advanced the industrial dynamics approach of Forrester to produce his "dynamic commodity cycle" model, which concentrated on the inventory formation aspect of market adjustments. Two coupled negative feedback loops, consumption and production, each act to adjust inventory coverage to desired levels. Another feature of the approach is that producers and consumers can employ any fuction of current and past prices to form expectations about future prices. In addition, functional relationships are expressed in continuous time with "period" analysis being replaced by "rate of change" analysis. Production and consumption are assumed to adjust continously to price changes rather than discontinuously between equilibrium points.

To apply system dynamics, it is preferable to select those commodities which display some form of cyclical behavior in production and prices. In the original Meadows (1970) study, models were constructed for hog, cattle, and broiler markets. Among recent applications, Hamilton (1979) has applied it to the coal market, Choucri (1981) to the oil market, and Strongman et al. (1976) to the copper market. A more general application to agricultural commodities was made by Linneman (1976) in the MOIRA model which represented a sequel to the "Limits To Growth" model.

Input-Output Models

Input-output models represent a conceptualization of economic production systems that reflect a relationship between inputs and outputs and intervening technical transformation. This form of model, however, cannot be employed directly to explain primary commodity markets. Rather it provides a disaggregated view as to how the demand and supply patterns for different commodities relate to the interindustry structure and aggregate or macroeconomic variables of a national economy. What makes input-output useful for commodity modeling is its simple theoretical structure which can interrelate industry inputs and outputs with the intermediate and final demands for primary commodities. However, the difficulties of obtaining individual commodity input-output entries have limited its usefulness. Modified or "eclectic" input-output models have thus been applied to analyze the impact of mineral, energy, and agricultural commodity industries.

An example of an attempt to employ this approach is that of Kruegar (1976) who explained how the future consumption of ferrous and nonferrous metals could be forecast by combining projections of material consumption ratios which related materials' consumption by individual industries to the demand for output of that industry. Components of the modeling structure thus included an estimate of GNP derived from a macro-forecasting model, estimated ratios reflecting materials' consumption per unit of industrial output for individual industries, and an input-output table which converted the economic estimates to production estimates and subsequently to the consumption of individual minerals.

Input-output models have also been applied to energy analysis, and in particular to the study of energy demand by Rose and Kolk (1987). Input-output has the particular advantage in this case of being able to deal with a larger number of primary and secondary fuels and their various demands all at once. Where it is possible to estimate shifts in the technical coefficients, Rose (1984) has shown that the impacts of new technology on energy production and conversion can be determined, including macroeconomic effects.

Among attempts to apply input-output to agricultural commodity analysis, one approach would analyze the impact of introducing new agricultural commodity export industries on the economic growth of developing countries, e.g. see Simpson (1980). This requires disaggregating or opening up the transactions or technical coefficients matrix to compute appropriate commodity output and income multipliers. The agricultural industry disaggregation takes place by obtaining budgets for industries which refer to processed primary commodities and by inserting them into the transactions matrix. The importance of these agricultural commodities stems from their level of export earnings as well as their domestic linkages. Thus, multipliers can be calculated showing the backward linkages of these products on country economies through the input-supplying industries.

IV. COMMODITY MODEL APPLICATIONS IN THE BANK

How have commodity model developments and applications within the Bank served Bank purposes and paralleled developments within the modeling profession itself? In other words how has Bank research been integrated with the development and application of the range of commodity modeling methodologies just discussed? The history of modeling activities at the Bank indicates that the majority of these methodologies has been employed by the Bank at one time or another. To understand these applications, it is thus interesting not only to examine earlier modeling efforts, but also to emphasize the more recent attempt to operate the models in a way so as to produce regular quantity and price forecasts over time.

In the discussion which follows the early model history is presented first for single commodity models and then for multiple commodity models. Current model applications are then divided according to the above econometric market modeling methodology and the mathematical programming methodology. Eergy market conditions recently experienced have featured such special modeling problems that this class of models is considered separately.

Early Model History

Among the earliest modeling work at the Bank, cocoa and rubber models were completed in the late 1960's in an effort to analyze commodity market stabilization.

Single Commodity Models. Results of a cocoa buffer stock stabilization effort were reported by Kim, Goreux and Kendrick (1975). This modeling attempt went beyond the then accepted technique of buffer stock simulation which attempted only to demonstrate what levels of buffer stock operation might be necessary to achieve various degrees of price stabilization. Instead it employed control theory such that levels of buffer stock operation could be selected which would be optimal from the point of view of stabilizing price as well as maximizing export revenue stabilization. A cocoa model also was constructed in that era by Yeung et al. (1979) based on adjustments in the market for cocoa beans and a similar study of the coffee market also was undertaken by de Vries (1975).

Some idea of the beginnings of rubber modeling in the 1970's can be obtained from Grilli et al. (1980). That model demonstrated the importance of analyzing rubber consumption by examining market shares of natural relative to synthetic rubber. Technological change proved to be an important factor in this analysis. Measurements of the extent of the substitution between natural and synthetic rubbers took place in relation to movements in relative prices. Although rubber production estimates were introduced exogenously, the model still provided an overall view of rubber market adjustments.

The first attempt to benchmark the progress of this early work took place in the form of the Aarhus conference held by the Bank in 1979 where some nine different models were evaluated, i.e., see World Bank (1981). Already a more advanced econometric rubber market model had been constructed by Grilli, Heterline and Pollak (1981). This time the major purpose was to simulate the impact of exchange rate and taxation policies on the supply and prices of natural rubber. The model dealt with several important issues which emerged as crucial in preparing medium-term forecasts. The first of these was the role played by changes in inventories and by changes in inflation in the formation of commodity price movements. Although exchange rate changes began to influence commodity prices more notably after 1972, these rates, together with taxation policies were found to have an important impact not only on revenue earnings of exporting countries but also on producer responses. In the case of rubber, these policies were found to influence longer-term market equilibrium. Longer-term adjustments were also captured in the model by quantifying substitution effects between synthetic and natural rubber. Total elastomer demand was first determined and then natural rubber demand derived using market share analysis. Petroleum prices, which suddenly became an important factor in synthetic rubber competition, also were included in the analysis.

Continuing efforts by the Bank to analyze buffer stock stabilization were continued in the econometric tin market modeling effort by Chhabra, Grilli and Pollak (1978). The International Tin Agreement, initially ratified in 1956, was at that time unique in that it employed a combination of buffer stock and export controls to keep prices within agreed price stabilization bands. The construction of the tin model which incorporated a buffer stock mechanism explained important price fluctuations not only by including the ITC buffer stock and industry stock holding but also by including stocks held by the U.S. General Services Administration.

While this feature enabled the modelers to simulate long term cyclical movements in tin prices and quantitites, underlying trend movements were also captured by incorporating substitution effects and producers' responses to market prices, the latter considered relative to long term mining cost changes. The tin model accurately captured long term declines in tin consumption due to competition from other materials (aluminum, steel, glass, plastic, etc.) as well as from technological changes in the use of tinplate, particularly in containers. The modeling efforts proved to the Bank that a parsimonious model (23 equations) could be constructed which would provide inexpensive simulation analyses regarding major commodity policies.

An econometric jute market model constructed by Anderson, Blitzer, Cauchois and Grilli (1981) also was concerned with buffer stock analysis, but other stabilization schemes were tested in the form of compensatory financing, taxation and tariffs, and crop area limitations. The policy importance of this effort resulted from the fact that Bangladesh, with one of the lowest incomes of the least developed countries, has provided the bulk of world raw jute exports and was a most likely candidate to receive financial support within the then existing context of UNCTAD's Integrated Program for Commodities. An innovative feature of this model was that the supply equations were formulated to reflect producer response to risk using Just's (1975) method of combining price variance measures with nonlinear regression techniques. Similar to Reutlinger's (1976) study within the Bank, the impact of alternative stocking rules was evaluated with a discounted flow analysis of stabilization benefits and costs.

The econometric tea market model built by Chung and Ukpong (1981) and reviewed at Aarhus reflected attempts to incorporate dynamic adjustments in forecasting long-term price movements. These adjustments included long term supply price response and the sensitivity of tea demand and supply to changes in coffee and fertilizer prices, respectively. This was one of the Bank's first models incorporating perennial tree crop variables in which commodity supply was determined by separate functional relationships for tree yields and area i.e. see Askari and Cummings (1976). The mature area response function thus depended on a 7-year gestation lag in tea prices, reflecting the investment response of tea planters. By introducing a dynamic compared to a static formulation of tea supply in the model, the Bank was thus able to provide a much more realistic analysis of tea market behaviour.

Multiple Commodity Models. The fats and oil model constructed by Augusto and Pollak (1981) was the first Bank model to be truly of a multi-commodity nature. The fats and oils market is extremely complex because its indigenous commodities include vegetable oilseeds, meals and oils as well as cattle and hog-fat derivatives and marine products. On the demand side, they are consumed in foods, animal feeds, soaps, paints and other non-edible products.

The model thus featured a variety of supply and export equations together with related import demand, price and inventory equations. The most interesting feature of this model was the linking of its various equations through a world oils and fats price index. The latter was endogenously determined in the model based on a simultaneous solution involving individual oils and fats price equations. Substitution between the various commodities also was achieved where relevant in the demand sector. This permitted long term projections for oils, fats and proteins to be generated while at the same time to provide consistent solutions among a large variety of oils and fats products.

The final of the Aarhus models is a developing country energy demand model constructed by Hoffman and Mors (1981). This model was intended to project energy demand for developing country regions based on individual country projections. The methodology adopted omits the supply side of the individual energy markets and instead estimates energy demand based on a wide set of determinants. Commercial energy demand was shown to be a function of per capita income, real energy prices, and structural variables; the latter include the shares of agriculture, mining and construction, manufacturing and electricity, and transport sectors in GDP. The particular character of this demand system was that it had been designed to interact with the Bank's overall macro-projections. This enabled the Bank to generate improved projections of world energy variables consistent with related country economic growth rates.

One final example of this early modeling work mentioned earlier has incorporated a number of commodity models into an integrated framework for country-individual macroeconomic projections as well as exports and world trade. The SIMLINK model developed by Hicks (1975) and described in Tims and Singh (1977) related the exports of developing countries to domestic investment levels and imports, and externally to the level of economic growth in OECD countries. The simultaneous solution of the various country and trade equations enabled projections to be made, for example, of import-constrained GDP growth rates or the real North-South resource transfer necessary to support a specified GDP growth rate. Among the 146 structural equations featured in the model, 79 equations represented 14 separate commodity market models (iron ore, fats and oils, copper, rice, sugar, beef, tin, cocoa. rubber, tea and coffee). Residual models were also included to explain the remaining commodity aggregates.

<u>Market Model Applications</u>

A turning point in commodity modeling occurred in the World Bank beginning in the 1980's. Modeling efforts became less experimental and more directly oriented to producing the kinds of commodity price forecasts essential to overall Bank efforts, as shown in Table 2. Attempts were also made to improve model realism, beginning with the revision of models dealing with perennial crops.

Agricultural Perennial Crop Models. Models of this type can be formulated on the supply side without considering the vintage capital stock adjustments actually involved in the planting, ageing and removal of trees. However, as suggested above and later by Akiyama and Trivedi (1985) and Trivedi (1986) including these dynamic adjustments permits a more accurate description of market behaviour. To this end, Akiyama and Bowers (1984) explored the use of gestation lags in examining the supply response of cocoa. The related future expectational variables used in the resulting supply equations were specified to reflect long run market clearing rational expectations. A similar approach was taken by Akiyama and Duncan (1982a) in explaining long-term adjustments in the cocoa market. This model in addition modeled cocoa demand growth in the industrial countries by incorporating constraints in the form of expected low population and income growth rates together with low elasticities of income and price. Market destabilization was shown to be a consequence of high demand and high prices relative to production growth, followed by periods of low demand and excess production.

This model was subsequently employed to prepare long term quantity and price projections as well as to analyze potential buffer stock stabilization policies proposed by the International Cocoa Organization (ICCO). The model performed this task not only by integrating buffer stock sales and purchases with industry stocks, but also by separating

TABLE 2

CHARACTERISTICS OF WORLD BANK COMMODITY MODELS

Commodity Model	Modeling Purposes	Modeling Structure	Empirical Scope	Model Contribution
Cocoa (1982)	Simulate market impacts of large production changes and of buffer stock stabilization schemes. Forecast long term quantity and price movements.	Competitive market including private inventories and public buffer stock adjustments. 30 equations (est.).	World. Annual 1961-78 and 1979-90.	Provide realistic view of current and future cocoa market adjustments.
Coffee (1982)	Simulate market impacts of large production changes. Forecast long term quantity and price movements.	Competitive market including inventory adjustments. 23 equations (est.).	World. Annual 1965-79 and 1980-90.	Provide realistic view of current and future coffee market adjustments.
Jute (1981)	Simulate buffer stock stabilization schemes. Simulate alternative stabilization policies including compensatory financing, tariffs and taxation, and crop area limitations.	Competitive market excluding inventory adjustment, but including buffer stocks. Supply equations include farmer response to risk. 39 equations (est.)	3 supply regions, 7 demand regions approximating World. Annual 1955-1975, 1976-1991.	Developed farmer supply equations which respond to price variance or "risk."
Tea (1981)	Simulate impact of long term structural changes in supply and sensitivity to coffee and fertilizer price increases. Forecast long term quantity and price movements.	Competitive market including including inventory adjustments. 56 equations (est.).	World. Annual 1957-79.	Supply equations combine area planted and yield sub-equations.
Tea (1986)	Simulate impact of changes in income, inflation, production subsidies and other exogenous shocks.	Competitive market including inventory adjustments and featuring a linear rational expectations approach to to market price determination. 43 equations.	World. Annual 1959-1983. Simulations 1984-2000.	Supply equations distinguish between long and short run adjustments. Rational expectations included in price formations.
Sugar (1980)	Forecast medium and long term movements in production, demand, trade and price based on baseline as well as conditional variable assumptions.	Competitive market including inventory adjustments. 67 equations.	World. Annual 1951-1977.	Trade equations included as well as production and demand equations.

Table 2 (continued)

Commodity Model	Modeling Purposes	Modeling Structure	Empirical Scope	Model Contribution
Sugar (1986)	Explain determinants of Cuba-USSR sugar trade arrangements and policies.	Bilateral market involving sugar export revenue maximization subject to trade balance requirements. 18 equations.	Cuba-USSR Trade. Annual 1960-1983.	Analyzes role of bilateral trade arrangement within world trade network.
Fats and Oils (1981)	Explain and forecast long term changes in the markets for fats and oils and high protein meals.	Competitive market where inventory adjustments provide a link between the markets for fats and oils and for high protein meals. 59 equations (est.).	World. Annual 1961-1977.	Multicommodity model with individual commodity prices simultaneously linked through a general oil price index.
Grains and Soybeans (1985)	Explain and forecast medium term changes of prices, trade, production, consumption and ending stocks for each commodity by country or region.	Competitive market featuring 12 commodity submodels with related country and regional detail and including cross-linkages between commodities. 1200 equations.	World. Annual 1960-81.	Large-scale multicommodity model with individual commodity prices simultaneously linked through export and import equilibrium.
Tin (1981)	Simulate buffer stock stabilization schemes. Forecast long term price price movements.	Competitive market including GSA and ITC stockpiles in inventory adjustment. 23 equations.	Industrialized and Developing Countries. Annual 1955-1975.	Constructed implied stocks variable to capture inventory effects. Supply equations depend on market price relations to mining cost responses.
Rubber (1981)	Simulate impact of exchange rate and taxation policies on the supply and prices of natural rubber. Forecast medium term price movements.	Competitive market including synthetic price substitution effects and inventory adjustments. 20 equations.	World. Annual 1957-1977.	Substitution between natural and synthetic rubber linked oil prices. Market share equations subsequently developed.
Rubber (1984)	Simulate impact of market stabilization along the lines of the International Rubber Agreement. Forecast long term rubber prices.	Competitive market including private inventories and public buffer stock adjustments. 87 equations.	World. Annual 1971-80 and 1982-86.	Employed distributed lag schemes in construction of rubber supply as well as demand equations.

Table 2 (continued)

Commodity Model	Modeling Purposes	Modeling Structure	Empirical Scope	Model Contribution
Iron and Steel: WISE (1981)	Forecast prices, demand and supply quantities of steel and requirements for major imports and investments in steel production facilities.	Competitive market with allocation achieved through linear complementarity programming (LCP). Investment depends on rational expectations. 13 equations.	Market economies plus steel balance in centrally planned economies. Benchmark years: 1970, 1975, 1980, 1985, 1990.	LCP model applied dynamically to achieve feedback from market price expectations investment behavior.
Iron Ore (1987)	Multiple analysis of the impact of iron ore capacity, steel production, scrap prices and MUV prices on iron ore consumption and production.	Competitive and non-competitive markets where bargaining at the contractural stage is a major price-determining force. Econometric model coupled with theories of bargaining and gaming.	World. Annual 1965-1984. Multiple analysis based on historical period.	Theories of bilateral oligopoly and principles of game theory as well as competition employed to determine price formation for iron ore during contractural negotiations.
Lead and Zinc (1983)	Explain and forecast equilibrium prices for lead and zinc, based on marginal cost pricing.	Competitive market with joint production employing linear programming (LP) such that lead-zinc production capacity matches demand requirements. Econometric equations estimate production and consumption variables.	World production, demand equilibrium. Benchmark year 1980. Structural equations estimated for 1962-80. Simulation. 1983-1990.	Determine minimum prices that will cover costs in development projects to determine growth.
Copper (1987)	Analyze evolution of world copper market in the medium and long term based on a variety of assumptions.	Competitive market including inventory adjustments. 57 equations.	World. Annual 1968-1983. Historical perspective since 1990s. Projection to 1990-1995.	Provides detailed impact analysis of structural change adjustments in the world copper market.
Fertilizer (1985)	Determine impact of price expectations on cyclical fluctuations in investment and prices.	Capacity adjustment or "supply side" model based on general autoregressive rational and static expectations.	World divided into four regions. Annual 1960-84.	Evaluate role of expectations in long-term commodity market adjustments.

Table 2 (continued)

Commodity Model	Modeling Purposes	Modeling Structure	Empirical Scope	Model Contribution
Energy Demand (1981)	Construct an energy demand model and projections method, such that the model could easily be linked to World Bank macro projections.	Demand equations based on sectoral shares in GDP. Equations stem from production functions employing labor, capital, energy and raw materials as factor inputs. 21 major regional equations.	World divided into 14 regions. Annual 1960-75.	Regional energy demands generated from sub-regions and country equations.
Energy and Petroleum (1984)	Simulate world energy and petroleum markets, based on OPEC pricing and economic growth assumptions known as the World Energy and Petroleum Model (WEPM).	Competitive market which allows for price-determining behavior of OPEC. Competitive equilibrium model forecasting price determination found only in the coal sector.	World including OPEC as a separate region. Annual 1960-78, 1985-2000.	Provides integrated outlook of interaction of OPEC prices with world energy market adjustments.
Coal (1985)	Simulate coal market impact of assumptions regarding economic growth, energy demands, oil prices and nuclear supply.	Competitive world energy market model (WEPM) which includes detail on coal market adjustments.	World. Annual 1960-78, 1985-2000.	Provides market equilibrium scenarios of coal demand and price adjustments.

the tree or acre investment decision from the current supply and price decision.

Further developments of the coffee model have been reported by Akiyama and Duncan (1982b). The supply side of the model combined stock adjustment equations for trees with those of yields to determine country production. The tree stock equations similar to the cocoa equations feature regressions of tree areas or stocks based on 2-4 year lagged real producer prices. The more important policy implications of this study relate to the impact of different rates of growth in cocoa production on the cocoa export prices and the export revenues of the coffee-exporting countries. Also related to cocoa production was the importance of coffee stock levels in exporting and importing countries.

The tea model constructed by Akiyama and Trivedi (1987) is the latest in this line of perennial tree crop models. This model represents an improvement over the previous perennial crop models in several respects. In addition to the mentioned vintage capital stock model, it incorporates new-planting decisions on the supply side for three leading producing countries. This specification makes it possible to distinguish explicitly between long-term and short-term producer responses to changes in exogenous variables. In addition, it adopts the above mentioned innovation of market-clearing rational expectations by including "forward-looking" price expectations in the price relationship. Greater disaggregation is also employed on the demand and supply side, and retail prices now play a role in the consumer demand equation. So far the model has been used on an experimental basis to evaluate the elasticities of price response and the impacts of supply shocks.

Other Agricultural Models. Sugar export revenues have always been of major importance for developing countries and thus sugar market modeling and forecasting have always been of interest to the Bank. The previous model developed by deVries (1980) and revised by Brook and Nowicki (1981) had been reconstructed to determine long term patterns of sugar consumption, production, prices and trade. The consumption-side of the model paid particular attention to the fact that the sugar income elasticity of demand is different at different income levels and that the sugar price elasticity of demand differs at various price levels. The production equation also employed lags not only to represent annual producer price response but also to take account of the 2-5 year gestation period required to expand processing capacity and to improve transport facilities. The price equation is strongly based on stock adjustments and features variable transformations which reflect world market balance and speculative stock adjustments.

Long term model simulations including confidence intervals for projected prices and conditional forecasts were prepared with respect to changing rates of income growth. Special attention also was given to the role of EEC and USSR sugar policies. In fact a separate study of the role of the USSR in the sugar market was undertaken by Tan (1986) to analyze Cuba-USSR sugar trade, employing a model which concentrated only on these countries by relegating all other trade as rest-of-the-world. Also studied were the implications of alternative world sugar price paths on the growth of the Cuban sugar industry and the country's related balance of trade.

A major attempt to construct a multicommodity grains model also occurred during this period. Mitchell (1985) describes this model as a non-spatial partial-equilibrium net-trade model; it includes detail on wheat, rice, coarse grains (maize, oats, barley, sorghum, rye, millet, and mixed grains), soybeans, soymeal and soyoil. Individual sub-models have been estimated for each commodity and country or region, with cross-linkages between each commodity. Each country model also takes the price from the world linkage mechanism and returns the level of net trade. Soybeans are modeled as beans in the production sector, but as beans as well as oil and meal in the consumption and trade sectors. This major modeling effort has not only included details in supply such as separating harvested areas and crop yields and including stock behaviour, but also has integrated the solutions of the various sub-models, amounting to some 1200 equations. The model also was constructed so that particular variables such as yields could be analyzed and modified by expert opinion. This interactive quality facilitates the Bank's approach to forecasting, which permits the integration of opinions from country experts in the preparation of forecasts.

Recently, global demand and supply for fertilizers has been added to the grains model (Buchinsky, 1987b). Demand for fertilizers (nitrogen, phosphate and potash) is driven by the demand for their use in the annual crops in the model. The supply side models investment decisions in fertilizer plant and incorporates the adjustment costs of changing the level of capital in the industry. Various assumptions regarding price expectations are tested (Choe, 1985 and 1987)

A rubber model constructed by Tan (1984), separated the rubber market into two submodels, one for natural rubber and one for synthetic rubber. The supply side of the model captures long term producer price responses similar to that featured in the above tea model. The demand side features relative natural rubber and synthetic prices similar to the Grilli et al. rubber model. Application of the model showed that the secular decline in natural rubber prices up to 1973 was due primarily to the substitution of natural rubber by less expensive synthetic rubber. After that period, high feedstock prices for synthetic rubber together with advances in radial tire design led to a recovery for natural rubber.

In addition to providing a basis for long term natural rubber forecasts, model simulations were performed to analyze the impact of a buffer stock policy under the Natural Rubber Agreement and to evaluate the role of changing Malaysian export taxes. Applications of this model reflect its ability to capture noncompetitive elements of synthetic rubber supply as well as to evaluate the influence of residual synthetic rubber stocks. Market stabilization also was found to depend strongly on the nature of the price band employed and of expected buffer stock operations.

Mineral Models. Among other recent modeling efforts, a new focus has been placed on the mineral commodities. A market model of the iron ore and steel markets constructed by Privolos (1987a and b) focuses on trade patterns and recognizes the bilateral oligopoly character of the main traders in the market. Price equations also link the international spot iron ore price to export prices and subsequently to producer prices. An important feature of this model is that it recognizes the importance of ore supply contract negotiations and subsequent bargaining processes in price formation. Bilateral oligopoly behavior is thus reflected in joint-profit maximization functions which are modeled employing game-theoretic algorithms. Applications of the model have been mostly short-term, using multiplier analysis to trace the channels of transmission of exogenous shocks such as capacity, scrap price changes, or exchange rates on iron ore market adjustments.

A model of the copper industry by Tan (1987) explores the impact of structural change on the copper market and thus will be useful for long-term price projections. While the model provides a comprehensive picture of the demand and supply sides of the market, the difficulty of determining capacity investment behavior required that this variable remained exogenous. Long-term scenarios have been generated by exploring differences between rates of economic growth as well as changes in the actual behaviour of individual countries.

Time Series Models. It is worth mentioning that several attempts have been made to enhance commodity model price forecasting with time series forecasting techniques. Studies by Bowers (1985) and Buchinsky (1987a) suggest potential not only for forecasting commodity markets but also as a basis for comparing commodity model validity and performance.

Programming Model Applications

Because problems of interregional transfers and process activities are less important to commodity price forecasting, this method has seen only limited attention in the Bank. However, it represented an important contribution to overall modeling efforts. Programming applications appeared early in the Bank, principally in work by Kendrick and Stoutjesdijk (1978) who used this approach to analyze and to plan industrial investment projects in developing countries. Their particular approach has been described above as mixed integer programming and permits the systematic screening of large numbers of alternative project configurations and the selection of those which are superior to others, a particular selection criterion.

The application of this technique requires simplified representation of both the set of productive activities under consideration and the environment in which this set of activities is to be performed. Such a representation normally necessitates the use of a large number of variables and parameters, some of a spatial nature, others of a technical or engineering nature. It is also necessary to decide upon a selection criterion on the basis of which a choice can be made from among the many alternative projects that are normally possible, most normally the criterion is cost minimization over time. Two large-scale model applications of this approach have appeared: one by Choksi, Meerus and Stoutjesdijk (1983) for the fertilizer industry and one by Kendrick, Meerus and Alatorre (1984) for the steel industry.

The mixed integer programming approach has also been applied to study investment planning in the aluminum industry by Brown and Dammert together with Meeraus and Stoutjesdijk (1983) in a research effort performed jointly with the OECD. The purpose of the model was to explain adjustments in aluminum investment and capacity, production and trade, subject to changes in the industry's operating environment. The latter included increased aluminum demand, higher investment costs in developing countries, increased hydropower costs in those countries, higher electricity prices in Canada, and limited or no trade among the major world blocks (OECD, LDCs, CMEA). It is obvious that this model contributes in its explanation of how smelting capacity adjusts geographically, as variations in the world energy situation influence each country's comparative advantage in energy.

The optimization of spatial allocation patterns also permits the Bank to analyze the impact of economies of scale on the sizing and timing of capacity expansion. The results of examining this impact with the aluminum model, however, were more normative than predictive. Instead of providing forecasts, the study employed sensitivity analysis, focusing on alternative aluminum demand forecasts, higher capital costs, varying cost and availability of electricity, and different trade strategies. While some emphasis is placed on the impact of tariffs and levies, recent increases in capital costs were shown to equal energy costs in investment decision-making.

Applications of programming models by the International Commodity Markets Division have extended to iron ore and steel and to lead and zinc as well. These models have embodied the spatial or trade dimension along with the processing and temporal dimensions of the investment problem. The WISE model of the iron and steel industry constructed by Hashimoto (1981) represents an earlier attempt to model investment behavior. This modeling exercise involved two features which placed it in the forefront of analyses of the iron and steel industry.

It was one of the first models to employ a new technique termed linear-complementarity programming, i.e. see Takayama and Hashimoto (1984). This permits the treatment of the two-way relationship existing between current investment and future market situations. That is, how is investment influenced by market expectations, and vice-versa? In this model investment in steel facilities has thus been explained dynamically with price expectations based on forward information. Here investment is assumed to be planned rationally, with perfect insight. The second feature of the model is that it is possible to make A-B comparisons regarding investment decisions based on rational expectations in relation to those decisions where industries are assumed instead to follow predetermined investment plans. Since investment plans must be made so far ahead in the steel industry, this alternative specification provides a more realistic approach to forecasting steel capacities, prices and production responses during swings in overall economic activity.

A related work on the iron and steel industry by Hashimoto (1982) dealt with the market influences of iron and steel scrap. Finally, the lead and zinc model constructed by Dammert and Chhabra (1987) utilized basic linear programming to determine the supply functions in markets where metals are mined as co-products. The programming submodel determined what should be the minimum lead and zinc prices that will cover the costs of production for the highest cost projects required to meet lead and zinc demand. These supply functions were then incorporated into industry models of an econometric market nature that included detail on lead demand inventories, secondary supply, scrap and prices for the major countries and geographic areas. In addition to giving a detailed perspective of an industry that has received very little modeling attention, the study provided the Bank with a basis for making medium to long-term projections. These projections were made more realistic by additionally considering market prospects, supply outlooks, costs of production and prices, and forward-linked industrial demands.

Special Case of Energy

The energy crises of the 1970s led the Bank to expand its modeling activities in the area of energy markets and fuel industries, because of the need to project energy prices and quantitites and to assess how developing countries might adjust to more expensive fuels. Oil-importing developing counties were likely to experience balance of payments and debt repayment problems; oil-exporting developing countries were likely to use their surpluses to finance new industrial and infrastructure projects. The need thus arose to construct a wide range of models employing a variety of methodologies capable not only of forecasting energy prices, but also of evaluating energy policy issues. The modeler's tasks were not easy because of the political nature of the oil price shocks and the difficulties of modeling noncompetitive and regulated market behaviour.

Among the energy modeling approaches which have been considered suitable for accomplishing these tasks, Labys and Wood (1985) report on the application of econometric models to describe the supply or demand of specific fuels or energy forms and to explain interfuel substitution. Engineering process models based on programming algorithms have been regarded as more suitable for describing the transformation of fuels and other primary inputs into refined products or energy derived products. Spatial and temporal equilibrium methods have extended the process approach, so as to improve the modeling of international trade flows in petroleum, coal and other fuels.

A somehat new methodology also appeared in the form of the optimization models described above, which analyzed past and prospective levels of OPEC production and pricing. These models were particularly concerned with noncompetitive or cartel behaviour on the part of OPEC members. Special emphasis was given to the determination of what could be considered the optimal trajectory for oil prices to follow over time. Such a trajectory would assure maximum returns to OPEC countries and provide consuming countries with a stable oil price to aid energy policy making.

Input-output models also were adapted to explain economy-wide transactions in energy terms. Such models provided the basis not only for comprehensive energy planning but also for examining energy-economy interactions. The fact that energy activities had a major impact on economic growth and vice-versa also led to the above mentioned model hybridization. In the end, most energy models emerged as some form of hybrid model, employing several different methodologies such as econometric and process engineering rather than a single methodology.

Regarding modeling activity in the Bank which commenced after the first oil price shock, Lambertini (1976) then began constructing an energy model capable of explaining energy market adjustments and of forecasting future energy needs in non-OPEC developing countries. A more complete global model based on econometric simulation methods was constructed subsequently and became known as the World Energy and Petroleum Model (WEPM), i.e., see Choe (1984). The model has three industrial country regions and four developing country groups (capital-surplus oil exporters, capital-deficit OPEC, non-OPEC oil exporters and oil-importing developing countries). The demand side of the model consists of three end-use sectors (transportation, industrial and residential/commercial) and one energy transformation sector (thermal power generation). The supply side featured endogenous supply specification only for coal; all other fuel supplies are determined exogenously. (Disaggregation into many components, of course, appears at the country, end-use, supply, and fuel product price level).

The model specification features more of a market equilibrium mechanism than a cartel approach for determining energy quantity and price changes. Because of the difficulty of determining OPEC prices endogenously, the model accepts OPEC price assumptions as given. OPEC's quantities then depend on its acting as a residual supplier, after world oil demand is first met by non-OPEC production. Given the OPEC price path and certain assumptions about GDP and population growth, the model generates energy balance projections as well as the discounted present value of revenues for OPEC as a whole and for its subgroups separately. The model's main applications have been to provide base-case projections of energy balances, energy demands, trade and prices for future years. Policy simulation analyses also have been performed to assess economic growth impacts and oil import tariff impacts. Finally various aspects of long-term OPEC pricing and production are explored.

The model appears to be more highly disaggregated on the demand side. Substitution is explained for a variety of fuels in a number of end-uses. In addition the fuel burning capital stock adjusts dynamically over time, based on the lags involved in retrofitting and in bringing newly constructed facilities into operation. The supply side is more restrictive with only coal supply being determined endogenously. The latter feature was made possible by the previous construction of an international coal market model by Choe (1985b). The fact that the other fuel supplies are exogenous could make the model more useful during times of market upheavel. As markets return to normality, one would expect more of a normal fuel supply-price response. But even here government regulation of the energy sector in many countries makes such a response difficult to model. It is believed that the model's projections might differ, if energy-economy feedback and non-OPEC supply responses were included. Nonetheless, the model has proven to be sufficiently realistic to provide useful energy projections and energy scenario impact analyses.

V. CONCLUDING PERSPECTIVE

This survey deals with international commodity market modeling so as to provide a perspective on the kinds of forecasting and project analysis needs that commodity models have met within the Bank. The time period covered reflects an era in which commodity modeling efforts within the Bank have not only paralleled those of the modeling profession itself but in some cases contributed to modeling advances. One would not expect these advances to be theoretical in nature and rightly so. Rather the advances have focused on improving model realism and on finding the best scientific means for accomplishing this task. Some examples of these advances include the incorporation of risk into the supply side of agricultural models, consideration of the influence of synthetic substitutes on commodity demand, integration of capital stock adjustment in modeling perennial tree crops, and embodiment of the influence of noncompetitive market structure in explaining oil price and trade patterns.

Of particular importance has been the attention given by the Bank in applying its models to produce a regular series of commodity price and quantity forecasts over an extended period of time. There are two difficult obstacles which have had to be overcome in this respect. The first has been to establish the technical means whereby models could be manipulated to generate commodity price forecasts on a regular basis. This means that the performance of these models must be maintained, despite problems of structural change and fortuitous shocks in commodity markets. The second has been to manage the forecasts and to publish them on a regular basis; this enabled forecast-users to understand the

Bank's forecast approach and to develop confidence in the forecasts themselves.

It was mentioned at the outset that commodity model building and forecasting is an extremely difficult activity. The methodologies and models reviewed, nonetheless, have pointed to considerable progress in the state of the art. Commodity modeling within the Bank has played an important role in commodity quantity and price forecasting and in project analysis and has contributed to advances in commodity modeling itself. There is thus much incentive for this activity to continue to be an important function within the Bank.

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