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World Non-Oil Primary Commodity Markets: A Medium-Term Framework of Analysis

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Summary

In this paper, the authors expand their earlier model of non-oil commodity price determination. The earlier study (Chu and Morrison, 1984) focused on the demand-side factors underlying the fluctuation of aggregate commodity prices in the short run. The present study discusses a medium-term framework for analysis of commodity price fluctuations. The study takes into account commodity production which is decomposed into two parts: potential production or capacity, representing producers' long-run decisions, and capacity utilization, representing their short-run decisions. Capacity is shown to respond to the medium-term price fluctuations, while utilization responds to the short-term fluctuations. The study shows how an initial price change caused by a change in demand can be eroded over time by the supply response to the initial price change. In this manner, the model captures the supply-price dynamics over the medium-term. This has several practical implications for medium-term analysis of prices and exports of primary products.

The study also analyzes short-term supply-side factors--such as changes in domestic prices and exchange rates of exporting countries--as well as demand-side variables--such as changes in economic activity, domestic prices and exchange rates of importing countries. The model traces the historical movements of commodity prices fairly closely, and confirms the authors' earlier findings that industrial production and domestic prices, adjusted for exchange rate changes, have been major factors underlying commodity price fluctuations since the early 1970s. The simulations based on the model also show that short-run supply changes reinforced demand-side factors during the two-commodity price cycles (1972-77 and 1979-84). The present study, however, goes beyond the previous analysis by measuring the extent to which inflation in exporting countries is transmitted to world commodity prices through the affects on costs. The study shows that in the short term, the prices of agricultural raw materials and metals are affected to a greater extent by inflation in exporting countries (through cost-push effects) than by inflation in importing countries (through substitution effects); the converse holds for food and beverages. The study also measures the impact of the global production shortfalls of food crops and the relatively slow pace of the economic recovery in Europe on the behavior of commodity prices after the 1981-82 recession.

World Non-Oil Primary Commodity Markets: A Medium-Term Framework of Analysis

I. Introduction

An earlier paper by the authors analyzed demand-side factors underlying the short-run fluctuation of non-oil primary commodity prices (Chu and Morrison, 1984). The analysis focused on the impact of economic activity, domestic prices, and exchange rates of industrial countries on the short-run fluctuation of non-oil commodity prices. The analysis showed that a large part of the fluctuation of non-oil commodity prices can be explained by the fluctuations of these demand-side variables. The analysis, however, did not adequately take into account the role of supply-side factors: both those relevant for the short-run fluctuation of commodity prices (e.g., supply shocks) and those relevant for the medium-term fluctuation (e.g., supply-price dynamics).

This paper presents a medium-term framework of analysis in which the the supply-price dynamics--the effect of current prices on future supplies through their impact on investments in productive capacity and the effect of capacity changes on commodity prices--is one of the building blocks. In addition, the paper deals with the role of supply shocks in the short-run fluctuation of commodity prices in a more systematic fashion than the earlier paper.

The rest of this paper is organized as follows. In Section II, the literature of supply-price relationships in primary commodities is briefly reviewed; in Section III, a model of supply-price dynamics is specified; in Section IV, the model is estimated for broadly disaggregated commodity groups; in Section V, the model is utilized to analyze the sources of commodity price fluctuations in the 1970s and the early 1980s; and Section VI summarizes the the analysis and results. The Annex extends the discussion of a number of topics not covered adequately in the main part of the paper.

II. Survey of the Literature

Most of the previous studies on the subject have addressed either the influence of supply on price, or the influence of price on supply, and they have for the most part analyzed these relationships for individual commodities. These studies, however, can provide a basis for the conceptual formulation of a more general model.

An early, rather simple model of supply-price dynamics was presented in the "cobweb theorem" (Ezekiel, 1938). In this model, output is determined by the price in the previous period. When combined with a demand function, the model produces the cobweb pattern of dynamic price movements. The cobweb model, with various adaptations, has been applied to a number of agricultural commodities (Dean and Heady, 1958; Harlow, 1960; French and Bressler, 1962). Most subsequent studies, however, have expanded on one or the other of the two-way causation between supply and price.

A number of studies assess the role of supply-side factors in commodity price fluctuations. Cooper and Lawrence (1975) discuss how supply-side factors tended to reinforce the commodity price boom of 1972-75, especially for food but also for agricultural raw materials and metals. The supply-side factors (output, stocks, and refinery capacity) in equations that explain changes in metal prices relative to manufactures prices are statistically significant; attempts to introduce supply variables for agricultural raw materials, however, were not successful.

Bosworth and Lawrence (1982) build on the analysis of Cooper and Lawrence and generally obtain more significant results from supply-side factors. For groups of commodities, a reduced-form equation derived from a rational expectations formulation relates the commodity prices deflated by manufactures prices to industrial production in market economies, production and stocks of the commodity, and a trend variable. Prices are shown to be most sensitive to production changes, the elasticity ranging between -1.5 and -2.0 for food and -4 for agricultural raw materials. For metals, the coefficients of stocks and capacity are both shown to be significantly negative, with elasticities of -0.4 and -0.9, respectively.

Hwa (1979) develops a dynamic disequilibrium model of price adjustment in competitive markets. The resulting price equation relates real commodity prices (deflated by manufactures prices) to world consumption and production of the commodity, lagged price, and a trend variable. This equation is tested for seven industrial commodities. The coefficients for both production and stocks are negative for all seven commodities.

Although these studies support the hypothesis of a statistically significant inverse relationship between commodity supply and price in the short run, they neither decompose these supply changes into changes in capacity (long-run) and in capacity utilization (short-run), nor identify the determinants of supply changes. These relationships are addressed in the present study.

The literature on the determinants of supply has focused on both short-run and long-run supply responses to price changes. In the case of annual crops, the short-run and long-run supply responses have been estimated with respect to total supply. In the cases of perennial crops and minerals and metals, 1/ changes in output have been decomposed into those attributable to changes in capacity utilization (short-run) and changes in the capacity itself (long-run).

1/ Hereafter, referred to as metals.

For agricultural commodities, a large body of literature on supply response originated from a basic model developed by Nerlove (Nerlove, 1958; Nerlove and Addison, 1958; Nerlove and Bachman, 1960). Nerlove's main contribution is to improve on the naive assumption of the cobweb model that farmers' price expectations are solely influenced by the current season's price. Nerlove (1950) postulates that producers are influenced by their perception of what is a "normal" price. Nerlove therefore uses the adapative expectation scheme used earlier by Cagan for a study of demand for money (Cagan, 1946). Desired output (or acreage) is specified as a function of the normal price and exogenous factors affecting supply, such as weather. To measure long-run supply elasticities, Nerlove uses basically the same equation with distributed lags and adds a time trend variable to represent factors such as technological change.

Many studies have since been conducted to estimate supply responses of individual commodities in individual countries. Several surveys of the studies have been compiled (Askari and Cummings, 1976; Askari and Cummings, 1977; Bond, 1983). Askari and Cummings report more than 600 estimates of supply elasticities based on Nerlove's model for different crops and countries. Although it is difficult to compare supply elasticities from different studies, the results generally conform to expectations: namely, first, long-run supply elasticities tend to be greater than short-run elasticities, and most of the numerical values of the elasticities are in the 0-0.3 range; second, the next largest number of estimates falls in the range of 0.34-0.67. One study shows that long-run supply or demand can be less price elastic than short-run supply or demand if uncertainty is introduced (Hoel and Vislie, 1983).

Following the Nerlove approach, many studies have included different variables to represent the influences of various non-market factors on supply. The most common of these variables are weather, represented by such measures as indices of rainfall, humidity, and frost. Parikh (1971) shows that non-market factors, such as rainfall, varietal improvements, expansion of irrigation, and total area under cultivation in the previous year, are important factors in determining output levels over time.

Risk or uncertainty is a factor that has generally been recognized to influence producers' behavior but ignored in most empirical studies. Just (1971), however, includes a risk variable to account for the influence of uncertainty regarding expected price on the supply of a number of annual crops in the United States. The study shows that risk is important in explaining acreage levels (a negative relationship), except for crops where significant government intervention in the market process exists.

For perennial crops, such as coffee and cocoa, rather major adaptations to the Nerlove model have been necessary (French and Matthews, 1971; Wickens and Greenfield, 1973; Bateman, 1965). As Wickens and Greenfield (1973) show, the supply decisions regarding a perennial crop (coffee) can be divided into two parts: long-run decisions regarding potential production (or supply) and short-run decisions regarding the proportion of potential production to be harvested in the current season (utilization of potential supply). The potential production function is derived from the Jorgenson-type investment theory, which yields a supply function similar to the basic Nerlove adaptive expectations model, with a distributed lag of current and past prices as explanatory variables. The short-term harvesting decision is determined by recent price levels (a short distributed lag of price) and the two-year bearing cycle for coffee. The total supply function is derived by adding the short-term harvesting function to the long-run investment function.

For metals, the total supply function can be divided into two parts: exploration and investment in mines (potential supply) and the rate of extraction from existing mines (utilization of potential supply). The literature on the determinants of the rate of extraction of existing mines can be traced back to Gray (1914), who derives an optimal rate of extraction based on maximization of average returns per unit cost. The study, recognizing the characteristic of exhaustible resources that present extraction represents a cost in terms of sacrificed future returns, shows that a higher interest rate results in a higher rate of present extraction.

Hotelling (1931) develops a dynamic optimization model, in which the rate of extraction is determined by maximizing the present value of discounted future net profits. This approach has been used by many subsequent authors with various modifications. Carlisle (1954) focuses on the decision concerning the optimal amount of the total deposit to be extracted, given that extraction costs first decrease, but then increase over time, and that the total amount of a deposit is never extracted.

Parish (1938) decomposes metal supply into the short-term rate of extraction and the long-term additions to capacity from investment in new mines. He shows that uncertainty and a high rate of interest encourage a higher current rate of extraction but discourage investment in new mines.

Herfindahl (1955) introduces the exploration function into the dynamic theory of metal supply. In his model, the basic determinant of the rate of both exploration and investment is expected profits. Given free entry and competition, prices tend to fluctuate around the long-run cost because of adjustments in investment, production, and price. Herfindahl (1967) provides empirical support for his theory by finding a significantly positive relationship between the rate of exploration and expected profit in the U.S. petroleum industry.

A recent study provides a representative model of total metal supply that includes many of the relationships that have been developed previously (Anders, Gramm, Maurice, and Smithson, 1980). Several modifications have been made to this basic model to account for special situations, such a monopoly, recycling, and the case of joint products. Regarding monopoly, Hotelling (1931) shows that monopolists tend to reduce the rate of extraction, but not the rate of exploration. However, various studies (e.g., Weinstein and Zeckhauser, 1975; Sweeney, 1975; Stiglitz, 1976; and Kay and Mirrlees, 1975) present examples of monopolies that extract at the same rate as, or more than, perfect competitors. Recycled materials, such as scrap copper, have become important sources of supply for many metals, especially in locations where pollution control costs are large. Schulze (1974) and Weinstein and Zeckhauser (1974) develop models whereby recycled supply is determined in a similar fashion to mined supply by maximizing the present value of expected profits. Finally, regarding joint products from the same deposit, Herfindahl (1955) shows that this complication makes it impossible to maximize discounted profit for each metal simultaneously.

The present study applies the common underlying approaches to supply responses adopted in previous studies to a study of aggregate commodity prices. Non-oil primary commodities have generally been shown to be characterized by competitive market conditions and profit-maximizing behavior of producers. Supply of individual commodities has been shown to be determined primarily by producers' profit expectations represented by a variety of commodity price and production cost formulations.

III. The Analytical Framework

1. An overview of price formation

World non-oil commodity markets are generally competitive, although distortions in respect of some commodities do exist. As in many other studies, therefore, the model introduced in this paper is a model of competitive price formation, rooted in the assumption that the market is cleared fairly rapidly and efficiently through adjustments in price. The analytical framework of the model is summarized in the following paragraphs.

Supply of commodities is determined as a result of producers' profit maximization and affected by shocks generated by non-economic factors (e.g., adverse weather). Demand for commodities is determined by world economic activity and the relative prices of commodities vis-a-vis the prices of substitutes. In addition, long-run factors (e.g., technological changes and population growth) may be important, but are not explicitly incorporated in the model in this paper. Supply may change as a result of either changes in potential supply (capacity) or in its utilization. The former is comparable to capacity output in manufacturing; the latter to capacity utilization. The analogy is obvious in the case of mining. However, as Wickens and Greenfield (1973) show, even for agricultural crops, similar comparisons may be made. 1/

The overall process of price determination presented in this paper may be summarized as follows. In the short run, prices are determined at the intersections of demand and supply schedules; the short run in this context is an interval of time too short for potential supplies to change, but long enough for the utilization to change. As shown later, it is useful to conceptualize an even shorter interval than this period; during this shorter interval, the supplies of most agricultural crops are fixed, while those of metals are price elastic. 2/ In the medium run, not only the utilization of potential supplies, but also potential supplies can change. Dynamic interactions between supplies and prices in a world of uncertainty, together with shifts in demand, set the stage for the medium-term fluctuation of commodity prices envisaged for metals by Herfindahl (1955): for example, low levels of supplies of commodities, reflecting capacity constraints caused by low levels of investments in earlier years, would raise prices above long-run average production costs; the high prices could encourage investment by affecting the expectation of future prices of existing, as well as new, producers, leading to an expansion of potential supply in later years, which reduces prices below the long-run average costs. This reduction of prices could then discourage investment and ultimately lead to capacity constraints. Therefore, in such a world, prices would tend to fluctuate around the long-run average production costs (including normal profits).

2. Determinants of supply

The concept "potential supply," or potential production in the context of the discussion in this paper, may be defined as the level of supply, or of production, that can be maintained with sufficient

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1/ The number and age distribution of trees (as in tropical beverages and rubber) are important determinants of potential supply, while the intensity with which the trees are harvested determines its utilization. For annual crops, the potential supply concept is less precise, although output obtained from land that is suitable for cultivation with current technology and normal weather could be considered analogous. To distinguish between potential supply and its utilization is important because their determinants are different. In the short run, the potential supply of primary commodities is predetermined; even in the production of annual crops, potential supply may not be easily changed, since a significant expansion of cultivable land requires substantial investments over a period of time. In contrast, the utilization of cultivable land can change easily if warranted.

2/ It should be noted that markets are still assumed to be cleared. In particular, no unintended stocks are assumed to be held by market participants.

economic incentives for the given level of fixed inputs under normal production conditions. 1/

The intended utilization of potential production is determined as a result of the short-run profit maximization of producers. In addition, actual utilization may change as a result of noneconomic factors: unusually good or bad weather may cause actual production to rise above or to fall below the normal level, thus raising or reducing utilization; a labor strike or civil disturbance could also cause utilization to decline. Actual production may exceed potential production if production conditions (e.g., weather) are more favorable than normal. 2/

Building upon the concepts discussed above, production is specified in the short run as a function of prices, supply shocks, and potential production:

$$(3.1a) \quad q_t^s = u_t + qc_t$$

$$(3.1b) \quad u_t = \alpha_0 + \alpha_1 rps_t + \alpha_2 rps_{t-1} + \alpha_3 ss_t$$

$$(3.1c) \quad rps_t = p_t + es_t - ps_t$$

where, in logs,

q_t^s = world production of a commodity,

u_t = utilization of potential production,

qc_t = potential production,

p_t = output price (representing international price of commodities in terms of U.S. dollars)

1/ For example, in the case of an annual agricultural crop, potential production is limited by the cultivable area and current technology; the area can be expanded by investments (e.g., land clearing) or reduced by abandonment. Increased research and development investments can improve yields through improved varieties; however, this process also takes years to bring results. In the case of tree crops, potential production is limited by the number and age distribution of trees that are regularly harvested; potential production may decline as a result of the abandonment of old trees, but may increase as a result of the reactivation of abandoned trees or maturing of new trees. In another example, potential production of a metal is limited by the production capacity of mines and refineries; potential production may decline as a result of the abandonment of uneconomical mines, but may increase as a result of reactivation of the uneconomical mines or opening of new mines.

2/ See Annex for further discussion of the concept of potential production.

es_t = exchange rates (vis-a-vis the U.S. dollar) of the currencies of exporting countries,

ps_t = domestic price levels in exporting countries,

ss_t = supply shocks, and

$\alpha_0, \alpha_1, \alpha_2, \alpha_3$ = coefficients ($\alpha_1, \alpha_2 > 0$; $\alpha_3 < 0$).

Equation (3.1a) defines world production of the commodity, while equation (3.1b) specifies the utilization ratio as a function of a distributed lag of real (output) prices faced by producers and supply shocks; Equation (3.1c) defines real prices faced by producers.

The change in potential production is specified as a function of average excess profits in recent years:

$$(3.2a) \qquad \Delta qc_t = \beta_0 + \beta_1 k^{-1} \sum_{i=1}^{k} erps_{t-i}$$

$$(3.2b) \qquad erps_t = rps_t - \overline{rps}$$

where

$\overline{rsp}$ = long-run average of rps_t, and

β_0, β_1 = coefficients ($\beta_1 > 0$)

k = parameter ($k > 0$).

Equations (3.2a) and (3.2b) specify the change in potential production as a function of the average excess profits, or the average real prices faced by producers in excess of their long-run average in recent years. Underlying this specification is the assumption that producers form the expectations of future prices on the basis of recent prices. As discussed earlier, it is assumed that over a sufficiently large number of years, average real prices should approximate the long-run average costs including normal profits. Equation (3.2b) therefore defines excess profits. Average excess profits in recent years result in an increase in potential production (through expansion by existing producers or entry of new producers); negative average excess profits result in a contraction of potential production. An increase in potential production may result either from excess profits during the years of distant past (e.g., maturing of new trees or completion of construction of mines) or from excess profits during the years of more immediate past (e.g., reactivation of old trees or old mines). Coefficient β_0 indicates the long-run rate of expansion of potential production. A positive β_0 implies that potential production expands even without excess profits; this phenomenon could result for various reasons (e.g., technological changes or government subsidization).

3. A model of supply-price dynamics

A complete system of equations, in change forms, may be constructed by adding a demand equation to the supply equations introduced in the preceding subsection as follows:

Supply

(3.1a)' $\Delta q^s_t = \Delta u_t + \Delta qc_t$

(3.1b)' $\Delta u_t = \alpha_0 + \alpha_1 \Delta rps_t + \alpha_2 \Delta rps_{t-1} + \alpha_3 ss_t$

(3.1c)' $\Delta rps_t = \Delta p_t + \Delta es_t - \Delta ps_t$

(3.2a)' $\Delta qc_t = \beta_0 + \beta_1 k^{-1} \sum_{i=1}^{k} erps_{t-i}$

(3.2b)' $erps_t = rps_t - \overline{rps}$

Demand

(3.3a) $\Delta q^d_t = \alpha_0 + \alpha_1 \Delta rpd_t + \alpha_2 \Delta y_t$

(3.3b) $\Delta rpd_t = \Delta p_t + \Delta ed_t - \Delta pd_t$

Equilibrium condition:

(3.4) $\Delta q^s_t = \Delta q^d_t$

Equation (3.3a) is a simplified form of the demand equation discussed in Chu and Morrison (1984), with the following notation:

q^d_t = quantity demanded,

ed_t = exchange rates of importing countries vis-a-vis the U.S. dollar,

y_t = industrial production (economic activity) in importing countries,

pd_t = domestic prices of importing countries, and

$\alpha_0, \alpha_1, \alpha_2$ = coefficients ($\alpha_1 < 0$, $\alpha_2 > 0$).

The system above can explain both the short-run and the medium-term fluctuation of prices. The whole system captures the dynamic interactions between supply and prices over a number of years during which potential production changes in reaction to the fluctuation of real prices. With potential production given as exogenous, the subsystem consisting of equations (3.1a)', (3.1b)', (3.1c)', (3.3a), (3.3b), and (3.4) captures the short-run determination of prices.

IV. Estimation Results

The model introduced in the previous section is sufficiently general to represent different types of primary commodities. In this paper, the model is applied to non-oil primary commodities classified into four broad groups: food, beverages, agricultural raw materials, and metals. The model is used to test a number of hypotheses on the short-run and the medium-run price formation in world commodity markets. 1/

1. Short-run fluctuations of prices and production

In the short run, producers accept predetermined levels of potential production; however, the utilization of potential production is determined as a result of producers' short-run profit maximization. Equation (3.1b), reproduced below, postulates that utilization depends both on current and lagged real prices, defined as the ratios of output (commodity) prices to domestic prices in producing countries, the latter being used as a proxy of input prices. The equation specifies utilization also as a function of supply shocks.

$$(3.1b) \quad u_t = \alpha_0 + \alpha_1 rps_t + \alpha_2 rps_{t-1} + \alpha_3 ss_t$$

Different characteristics of production, however, yield different supply schedules. For food crops, including beverages, production decisions are made at the beginning of a crop year, and it is not easy for producers to revise the production plans during the course of the year. For industrial raw materials including several agricultural raw materials (e.g., natural rubber, timber, and wool) 2/ and metals, production plans can be revised fairly easily. It is also true that, while supply shocks are a dominant factor in the production of food crops, they are

1/ See Annex for a description of the structure of world non-oil primary commodity markets and of the statistical data used in the study.
2/ Except for such annual crops as cotton and jute.

relatively less important for industrial raw materials. The utilization equation may, therefore, have two different forms for the group of food crops and for the group of industrial raw materials:

Food crops

(3.1b.i) $\Delta u_t = \alpha_0 + \alpha_2 \Delta rps_{t-1} + \alpha_3 ss_t$

Industrial raw materials

(3.1b.ii) $\Delta u_t = \alpha_0 + \alpha_1 \Delta rps_t + \alpha_2 \Delta rps_{t-1}$

The two groups of commodities may also differ in their demand schedule--food crops with relatively low elasticities of demand with respect to economic activity and industrial raw materials with relatively high elasticities.

These differences in the supply and the demand schedules are the causes of the differences in the short-run price behavior for the two commodity groups. For food crops, annual price fluctuations are largely determined by the annual fluctuation of production as a result of lagged price changes and supply shocks; for industrial raw materials, they are largely determined by shifts in demand. Therefore, for the former group, the fluctuation of prices should be correlated negatively with production fluctuations; for the latter group, price fluctuations, being primarily driven by shifts in demand, should be positively correlated with production fluctuations.

This short-run price-production relationship may be empirically tested. In the results reported in Table 1, the rate of change in production is negatively correlated with changes in real prices in the case of food crops, but positively correlated for industrial raw materials (Part A). For both groups, the correlation is fairly low (adjusted R^2 of 0.121) for food crops and 0.195 for industrial raw materials, but the relationships are statistically significant (at the 95 percent level for the former and at the 99 percent level for the latter).

The effects of lagged real prices on the utilization ratio are positive for both food crops and industrial raw materials, although for the latter group the coefficient is not statistically significant (Part B, Table 1). These results suggest the importance of the lagged real price variable in the determination of the utilization of potential production for the food crop group, while indicating that lagged real prices may not be a significant factor in the determination of the utilization of potential production for the industrial raw material group. As mentioned earlier (p. 10), the greater ability of industrial raw material producers to adjust utilization in the short run suggest that current real prices may be a more significant determinant of current production.

Table 1. Short-Run Price-Production Relationships 1/

	Dependent Variables: Rate of Change in	Sample Period	Coefficients for Explanatory Variables All in Rate of Change: Constant terms	Production (Δq_t^s)	Lagged real prices (Δrps_{t-1})	$\bar{R}^2$	DW	SEE
			(Part A)					
Food crops 2/	Real prices (Δrps_t)	1962-82	0.014 (0.51)	-0.923* (-2.58)		0.121	1.86	0.173
Industrial raw materials 3/	Real prices (Δrps_t)	1962-82	-0.062 (-2.67)	2.144** (3.31)		0.195	1.99	0.124
			(Part B)					
Food crops 2/	Utilization (Δu_t)	1962-82	0.023 (1.97)		0.135* (2.18)	0.087	2.72	0.074
Industrial raw materials 3/	Utilization (Δu_t)	1962-82	-0.002 (-0.37)		0.025 (0.87)	0.006	2.59	0.025

1/ Regression based on pooled time series, cross sectional annual data; within each group (agricultural crop group and industrial raw material group), time series for subgroups (food group and beverages group for the former and agricultural raw material group and metal group for the latter) are pooled together for the regression.

2/ Includes beverages.

3/ Consists of agricultural raw materials and metals.

* Significant at 5 percent; ** at 1 percent.

2. Determinants of the changes in potential production 1/

In the previous subsection, the equation for the changes in potential production is specified as:

$$(3.2a) \qquad \Delta qc_t = \beta_0 + \beta\, k^{-1} \sum_{i=1}^{k} erps_{t-i}$$

$$(3.2b) \qquad erps_t = rps_t - \overline{rps}$$

where 'k' is an unspecified parameter, which should reflect the gestation period of capital investments for potential production. Although it is generally known that the gestation periods are longer for beverages and metals than for food and agricultural raw materials, it is difficult to pinpoint the value of parameter 'k' for each commodity group particularly because each group consists of fairly heterogeneous commodities. 2/ Therefore, in this paper, the value of 'k' is empirically searched for each group. The estimated parameters for the four groups of commodities, together with the values of 'k,' are reported in Table 2.

The value of 'k' is smaller for the commodity groups with relatively short gestation periods of capital investment (food and agricultural raw materials; four and five years, respectively) than for the commodity groups with relatively long gestation periods (beverages and metals; seven years for both), confirming the hypothesis based on the nature of production technologies. The regressions also reveal strong long-run upward trends in potential production, probably resulting from the long-run expansion of demand for commodities. The long-run trend rate of annual increase in potential production ranges from 1.2 percent for beverages to 3.4 percent for food and metals. Around these long-run upward trends, the rate of change in potential production fluctuated as

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1/ See Annex for a description of potential production data for the four groups of commodities.

2/ Two groups of commodities, beverages and metals, are similar in that commodities in these two groups are characterized by relatively long gestation lags (i.e., five years or more). Regarding the food group, approximately 80 percent of the weight is accounted for by annual crops and commodities that approximate annual crops (i.e., bananas, sugar, and fishmeal). The remainder of the food group consists of some perennial crops (i.e., copra and palm oil) and commodities with special supply charactersitics (i.e., beef and lamb). It should be mentioned, however, that even with annual crops, substantial increases in potential production may take considerable time related to land clearing and investments in research and development. Finally, agricultural raw materials is the most heterogenous group, consisting of pure annual crops, perennial crops, and commodities with special supply characteristics, the last group accounting for more than half of total weight.

Table 2. Determinants of the Changes in Potential Production

		Coefficients							
	Sample Period 1/	Constant	Time trend (t)	Average excess profits $(k^{-1} \sum_{i=1}^{k} erps_{t-i})$	K	Correction of Error Term 2/	$\overline{R}^2$	DW	SEE
Food	1964-82	0.034** (16.88)		0.034* (2.31)	4	CO(1)	0.341	1.85	0.006
Beverages	1968-82	0.012** (10.19)		0.080** (8.48)	7	CO(1)	0.742	2.15	0.006
Agricultural raw materials	1965-82	0.034** (15.07)	-0.001** (-8.46)	0.011 (1.08)	5		0.842	1.94	0.003
Metals (1)	1968-82	0.013** (4.02)		0.169** (5.22)	7		0.652	0.59	0.011
(2)	1968-82	0.002 (0.64)		0.067 (2.06)	7	CO(4)	0.732	1.73	0.005

1/ Starting points of the sample periods differ because of the differing values of K.
2/ "CO" means Cochrane-Orcutt correction of the error term, with the figures in the parentheses indicating the order of the autoregressive equations for the error terms.
* Significant at 5 percent; ** at 1 percent.

a result of the fluctuation of average past excess profits, as defined by equation (3.2b). The excess profit variable is statistically significant for food, beverages, and metals; it is shown to a have positive, but statistically insignificant, effect for agricultural raw materials. The estimated coefficients range from 0.011 for agricultural raw materials to 0.169 for metals; the coefficients are 0.034 for food and 0.080 for beverages. The explanatory power of the equation is the highest for agricultural raw materials and the lowest for food. The adjusted R^2 for the former is 0.842; for the latter, 0.341. For agricultural raw materials, average excess profits contribute little to the explanatory power; the second-degree polynominal time trend accounts for a large part of the variation in potential production. 1/

Since the early 1970s, the expansion of potential production decelerated significantly for agricultural raw materials and metals, while it slowed down only slightly or accelerated for food and beverages. The annual rate of expansion of potential production was 3.9 percent and 1.2 percent for food and beverages during 1962-71; potential production for these two commodity groups continued to expand at similar rates during 1972-82. The rate of expansion of potential production, however, decelerated sharply for the other two groups, from 2.7 percent to 1.1 percent for agricultural raw materials and from 4.3 percent to 1.0 percent for metals. The estimated equations suggest that the major factor underlying the disparate behavior of potential production was the different profiles of excess profits. The average excess profits changed from negative to positive for food and beverages between 1962-71 and 1972-82; they changed from positive to negative for agricultural raw materials, and declined sharply for metals (Table 3). 2/

3. Determinants of short-run equilibrium prices

In the formation of short-run equilibrium prices, potential production is predetermined. In addition, for agricultural crops, even the utilization of potential production is determined by either exogenous (supply shocks) or other predetermined (lagged and real prices) variables. Therefore, the reduced-form price equations derived from the system introduced in Section III may be written as follows: 3/

1/ The constant term in equation (3.2a), estimated results of which are reported in Table 2, is the long-term trend growth in potential production; the coefficient for time trend is the coefficient for time trend squared in an equation for the level, not changes, of potential production.

2/ In addition to the average excess profits, the role of risk in producers' decisions to change potential production has also been tested. For such a test, the index of instability in real commodity prices in recent years was used as a proxy for the future risk relating to investments. The test, however, did not yield positive results. The results perhaps reflect the fact that risk is fairly commodity specific and not amenable to testing on aggregate levels.

3/ Food crops include beverages; for individual raw materials the coefficient $\alpha 2$ for lagged real prices in the demand equation is suppressed.

Table 3. Changes in Potential Production and Excess Profits

	Changes in Potential Production				Average Excess Profits	
	1962-82	1962-71		1972-82	1962-71	1972-82
		Whole period	Subperiod		Subperiod	
Food	3.7	3.9	3.6 (1964-71)	3.5	-2.4 (1964-71)	3.8
Beverages	1.4	1.2	0.2 (1968-71)	1.7	-8.7 (1968-71)	3.7
Agricultural raw materials	1.9	2.7	2.5 (1965-71)	1.1	-0.9 (1965-71)	-1.7
Metals	2.6	4.3	4.5 (1968-71)	1.0	13.0 (1968-71)	0.5

Food crops

$$(3.5a) \qquad \Delta p_t = \theta_0 + \theta_2(\Delta pd_t - \Delta ed_t) + \theta_3 \Delta q_t + \theta_5 \Delta y_t$$

with $\theta_0 = \frac{\gamma 0}{\gamma 1}$, $\theta_2 = 1$, $\theta_3 = \frac{1}{\gamma 1} < 0$, and $\theta_3 = \frac{\gamma 2}{\gamma 1} > 0$.

Industrial raw materials

$$(3.5b) \qquad \Delta p_t = \theta_0 + \theta_1(\Delta ps_t - \Delta es_t) + \theta_2(\Delta pd_t - \Delta ed_t) + \theta_4 \Delta qc_t + \theta_5 \Delta y_t$$

with $\theta_0 = \frac{\gamma 0 - \alpha 0}{\alpha 1 - \gamma 1}$, $\theta_1 = \frac{\gamma 2}{\alpha 1 - \gamma 1} > 0$, $\theta_2 = - \frac{1}{\alpha 1 - \gamma 1} > 0$,

$\theta_4 = - \frac{1}{\alpha 1 - \gamma 1}$, and $\theta_5 = \frac{\gamma 2}{\alpha 1 - \gamma 1} > 0$.

The estimated reduced-form price equations (3.5a) for the food crop groups are reported in Table 4 (Part A). In estimating equation (3.5a), the constraint $\theta_2 = 1$ is imposed by transposing $\Delta pd_t - \Delta ed_t$ to the left-hand side of the equation and defining a new dependent variable $\Delta p_t - (\Delta pd_t - \Delta ed_t)$. In addition, two dummy variables (d_{1t}, d_{2t}) are included in the equation for beverages to account for persistent price increases that followed two consecutive production shortfalls in 1972-73 and 1975-76. 1/

As expected, the estimated price equations indicate that production is the dominant factor in annual fluctuations of food and beverage prices. Economic activity (industrial production) in consuming countries is shown to be fairly significant, although the t-ratios are lower than those for the production variables. It should be noted that underlying the specification of the equations is a maintained hypothesis that inflation ($\Delta pd_t - \Delta ed_t$) in importing countries is a significant variable in the determination of commodity prices.

1/ Beverage prices increased by 18 percent in 1974, after rising by 21 percent in 1973, in response to the large production shortfalls in 1972-73, although production recovered significantly in 1974. Similarly, prices increased by 55 percent in 1977, after rising by 65 percent in 1976, in response to production shortfalls in 1975-76, although production recovered significantly in 1977. The persistent price increases possibly resulted from low levels of stocks during initial months of 1974 and 1977. This phenomenon is accounted for by the dummy variables.

The reduced-form price equations for agricultural raw materials and metals have two variables which are highly correlated: inflation in exporting countries ($\Delta ps_t - \Delta es_t$) and that in importing countries ($\Delta pd_t - \Delta ed_t$) are correlated for both groups of commodities because industrial countries dominate in both exports and imports of these commodities. Because of this multicollinearity, to simply regress Δp_t on the two inflation variables and other explanatory varibles would not yield valid statistical results for the two inflation variables. To test the separate effects of inflation in exporting and importing countries on commodity prices, the following procedures are used:

First, it is noted that θ_1 and θ_2 in equation (3.5b) should sum to unity. The equation may therefore be rewritten as:

$$(3.5c) \quad \Delta p_t - (\Delta pd_t - \Delta ed_t)$$
$$= \theta_0 + \theta_1(\Delta ps_t - \Delta es_t - \Delta pd_t + \Delta ed_t)$$
$$+ \theta_4 \Delta qc_t + \theta_5 \Delta y_t$$

Although estimating equation (3.5c) does not give rise to the multicollinearity problem, the effect of the inflation variables ($\Delta ps_t - \Delta es_t$, $\Delta pd_t - \Delta ed_t$) cannot be assessed separately. For such an assessment, the coefficients obtained from the estimated (3.5c) are used to derive the following two equations:

$$(3.5d) \quad \Delta p_t - \theta_0 - \theta_2(\Delta pd_t - \Delta ed_t) - \theta_4 \Delta qc_t - \theta_5 \Delta y_t$$
$$= \theta_1(\Delta ps_t - \Delta eb_t)$$

$$(3.5e) \quad \Delta p_t - \theta_0 - \theta_1(\Delta ps_t - \Delta es_t) - \theta_4 \Delta qc_t - \theta_5 \Delta y_t$$
$$= \theta_2(\Delta pd_t - \Delta ed_t)$$

The estimation results for equations (3.5c), (3.5d), and (3.5e) are reported in Table 4 (Part B). The value of the coefficients θ_1 suggested by the estimated Equation (3.5c) are 0.663 for the agricultural raw material group and 0.582 for the metal group. The equation being based on the redefined inflation variable, the statistical nonsignficance of the coefficient of the inflation variable is not a valid result on the the impacts of world inflation on commodity prices. On the contrary, the significance of the inflation in both exporting and importing countries for the commodity price fluctuations is well demonstrated by the second-step regressions of Equations (3.5d) and (3.5e), for both agricultural raw materials and metals. Being based on small samples, the second-step regressions do <u>not</u> yield estimates of θ_1 and θ_2 that sum to unity.

Table 4. Reduced-Form Price Equation

	Sample Period	Equation	Constant θ_0	Coefficients for: Inflation differential 1/ $\Delta pes_t - \Delta ped_t$ θ_1	Inflation 1/: Producing countries Δpes_t θ_1	Inflation 1/: Consuming countries Δped_t θ_2	Supply: Production Δq_t θ_3	Supply: Potential production Δqc_t θ_4	Industrial production Δqc_t θ_5	Dummy variables d_{1t}	Dummy variables d_{2t}	$\bar{R}^2$	DW	SEE
							(Part A)							
Food	1962-82	3.5	0.034 (0.72)			1.0	-2.523** (-2.08)		1.259 (2.05)			0.367	1.66	0.133
Beverages	1962-82	3.5	-0.089 (-1.92)			1.0	-1.318** (-3.55)		1.570 (1.85)	0.240 (1.46)	0.705** (4.22)	0.538	2.25	0.153
							(Part B)							
Agricultural raw materials	1962-82	3.5c	-0.047 (-1.07)	0.663 (0.82)				-6.582* (-2.66)	3.404** (5.40)			0.588	1.81	0.091
		3.5d			0.860** (3.66)							0.312	1.86	0.083
		3.5e				0.484* (2.37)						0.185	1.88	0.083
Metals	1962-82	3.5c	-0.057 (-1.72)	0.582 (0.71)				-2.132 (-1.710)	2.594** (0.821)			0.460	1.75	0.089
		3.5d			0.802** (3.63)							0.318	1.67	0.080
		3.5e				0.593* (3.00)						0.264	1.67	0.080

1/ $\Delta pes_t = \Delta ps_t - \Delta es_t$, $\Delta ped_t = \Delta pd_t - \Delta ed_t$; real price exchange rates.

* Significant at 5 percent; ** at 1 percent.

It is noteworthy, however, that for both groups, the average of the θ_1 from equation (3.5d) and $(1-\theta_2)$ derived from equation (3.5e) are close to estimates of θ_1 based on equation (3.5c). It is also noteworthy that the sizes of the impacts of inflation in exporting countries on commodity prices are greater than that of importing countries for both agricultural raw materials and metals, thus suggesting the importance of the cost-push effects on commodity price increases.

An interesting by-product of the results discussed so far are the estimates of the coefficients of the simple structural models that yield the reduced-form equations. Table 5 reports the values of these estimates. It should be noted that for food and beverages, the price elasticity of supply is constrained to be zero. The price elasticities of demand are estimated at -0.396 for food and -0.758 for beverages. For agricultural raw materials and metals, the price elasticities of supply (0.101 and 0.273) are estimated to be larger than those of demand (-0.051 and -0.196).

The elasticity of demand with respect to economic activity ranges from 0.500 for food to 1.119 for beverages. In Table 5, the estimated reduced-form coefficients for the inflation and the economic activity variables are aggregated on the basis of the export value shares for 1979-81. Constrained to sum to unity, the coefficients for the inflation terms are estimated at 0.267 for the inflation in exporting countries and 0.733 for the inflation in importing countries. The coefficient for the industrial production variable is estimated at 2.040. An earlier study by the authors (Chu and Morrison, 1984) suggested 1.2 for the coefficients of the inflation in industrial countries and 2.0 for the industrial production. Thus, the results of the present study are broadly comparable with the earlier study, but the present study delineates the channels through which inflation in industrial countries is transmitted to world commodity markets. Contrary to the implications of the earlier study, the present study suggests that only about 70 percent of the inflation in industrial countries is transmitted through the substitution channel, while the rest is transmitted through the cost-push channel; this result reflects the fact that the industrial countries are dominant exporters of primary commodities.

V. Supply-Price Dynamics and Commodity Price Fluctuation

In this section, a model of supply-price dynamics is used to analyze how various supply and demand shocks give rise to commodity price fluctuations. Subsection 1 assesses the model's capability to trace the historical paths of commodity prices. Subsection 2 analyzes the sources of commodity price instability since 1969. Subsection 3 discusses how prices respond to a demand shock; the simulation thus shows indirectly how supplies and prices interact dynamically, often intensifying the impacts of short-run disturbances on commodity prices. Subsection 4 shows how the model can be used to simulate the 1983-84 commodity price recovery.

Table 5. Estimates of the Reduced-Form and the Structural Equation Coefficients

	Sample Period	Weights in Overall Index	Dependent variable	Coefficients: Production Δq_t	Inflation: Exporting countries $(\Delta ps_t - \Delta es_t)$	Inflation: Importing countries $(\Delta pd_t - \Delta ed_t)$	Potential production Δqc_t	Industrial production Δy_t	Dummy variable 1 d_{1t}	Dummy variable 2 d_{2t}
Total Non-Oil		1.00								
Reduced form for price 1/			Δp_t		0.267	0.733		2.040		
Food	1962-82	0.43								
Reduced form for price 1/			Δp_t	-2.523		1.0		1.259		
Structural equation: demand			Δq_t			-0.396		0.500		
Beverages	1962-82	0.14								
Reduced form for price			Δp_t	-1.318		1.0		1.570	0.240	0.705
Structural equation: demand			Δq_t			-0.758		1.119		
Agricultural raw materials	1962-82	0.21								
Reduced form for price			Δp_t		0.663	0.337	-6.582	3.404		
Structural equation: supply			Δq_t		0.101		1.0			
demand			Δq_t			-0.051		0.520		
Metals	1962-82	0.22								
Reduced form for price			Δp_t		0.582	0.418	-2.132	2.594		
Structural equation: supply			Δq_t		0.273		1.0	0.700		
demand			Δp_t			-0.196				

1/ Derived as weighted averages of the coefficients for individual groups.

1. The model

The system estimated in the previous section for four groups of commodities form a larger system for the non-oil primary commodities as a whole. With such a model, overall commodity prices may be simulated on the basis of the simulated prices for individual commodity groups.

The system is summarized in Table 6, and the summary statistics of a dynamic simulation for commodity prices based on the historical values of the exogenous variables, including the estimated supply shocks for food and beverage prices, are reported in Table 7. 1/ In addition, the actual and simulated values of overall commodity prices are compared in Chart 1. The system traces the movements of commodity prices fairly accurately. 2/ It should be noted, however, that for food and beverages, these results in large part come from the fact that the estimates of the realized supply shocks are used as exogenous variables. The dynamic simulation results should, therefore, not be interpreted to be an indication of the forecasting ability of the model, since the values of future exogenous variables, including supply shocks would not ordinarily be known. 3/

2. Analysis of the sources of commodity price instability

The model incorporates a number of sources of commodity price instability. On the supply side, supply shocks for food and beverages and domestic prices and exchange rates of exporting countries for all four groups of commodities are included. On the demand side, economic activity (industrial production) of importing countries and their domestic prices and exchange rates are included. To assess the extent of the contributions made by these variables to the instability of the overall commodity prices, prices are simulated on the basis of the assumptions that each of these variables had been completely stabilized one at a time at their long-term trends.

Such an assessment could be made in either of two ways: (i) a comparison can be made of the simulation results based on two alternative time paths (one historical and the other fully stabilized) of an exogenous variable with all the other exogenous variables assuming historical values, but the error terms of all the stochastic equations replaced by zeros; and (ii) a comparison can be made of the simulation results based on the same assumptions as in (i) except that the residuals of the stochastic equations (as estimates of the error terms) assume historical values. The latter method is used in this section; therefore, "simulated prices" with historical values of exogenous variables are

1/ The estimation procedures for the supply shocks are explained later in this section.

2/ See Annex for additional details of the simulation results.

3/ See V.4 for an application of the model to make projections. One of the difficulties is that the size of supply shocks is not known at the time of the projections. In practice, an early estimate of the forthcoming crop might be used as a proxy for the size of supply shocks.

CHART 1

COMMODITY PRICES: ACTUAL AND SIMULATED, 1969-82

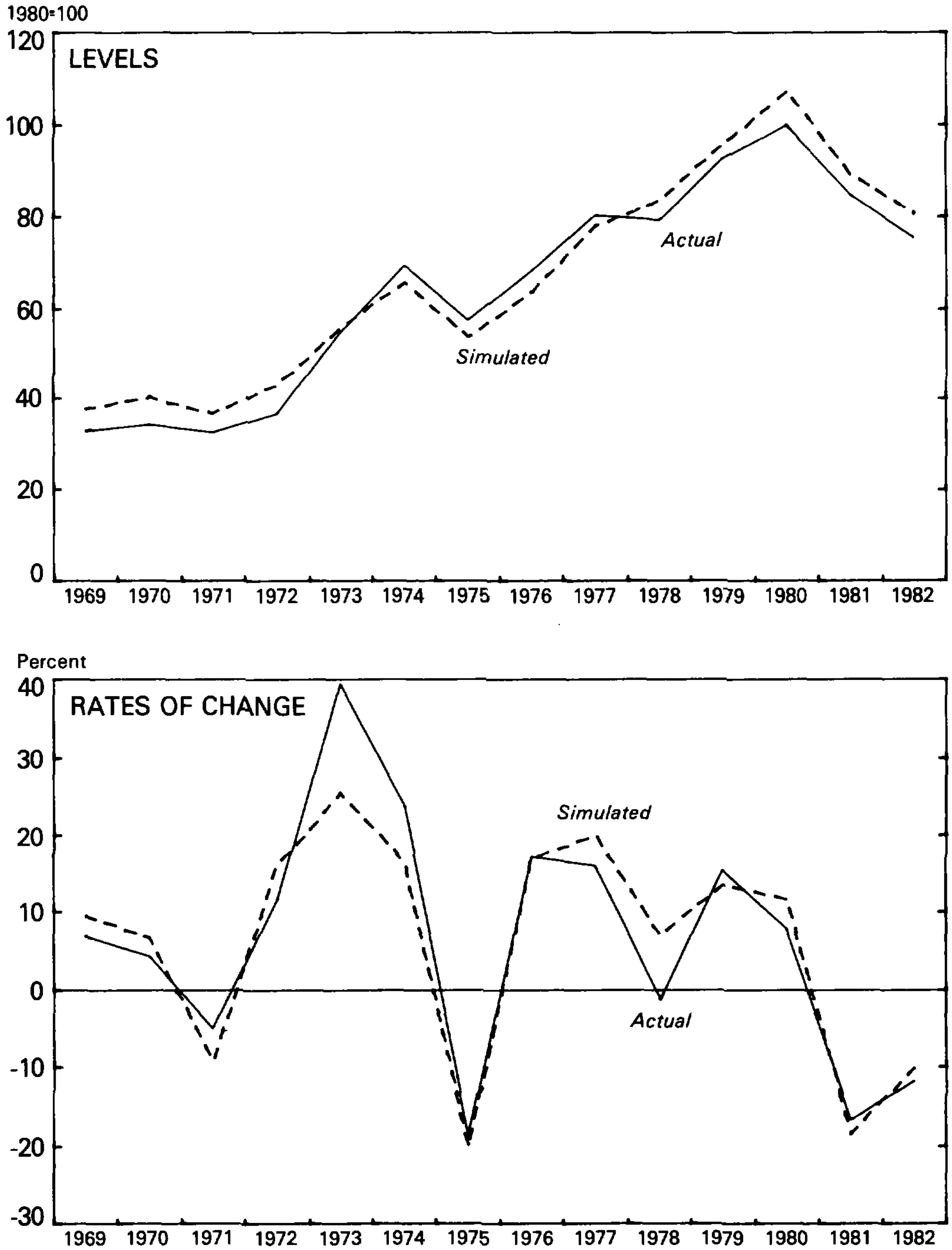

Table 6. The Estimated Model

Dependent variable	Equation No.	Equations
		<u>Overall Commodity 1/</u>
Production		$\Delta q = 0.430\Delta qf + 0.140\Delta qb + 0.210\Delta qa + 0.220\Delta qm$
Potential production		$\Delta qc = 0.430\Delta qcf + 0.140\Delta qcb + 0.210\Delta qca + 0.220\Delta qcm$
Utilization		$\Delta u = \Delta q - \Delta qc$
Price		$\Delta p = 0.430\Delta pf + 0.140\Delta pb + 0.210\Delta pa + 0.220\Delta pm$
		<u>Food</u>
Production	3.1a	$\Delta qf = \Delta qcf + \Delta uf$
Potential production	3.2a	$\Delta qcf = 0.034 + 0.034 cepsf + \varepsilon_{f1}$
		$\varepsilon_{f1} = 0.349\varepsilon_{f1-1} + \omega_{f1}$
Utilization	3.1b	$\Delta uf = 0.004 + 0.046\Delta rpsf_{-1} - 0.089 df + \varepsilon_{f2}$
Average excess profits		$cespf = (epsf_{-1} + epsf_{-2} + epsf_{-3})/3$
Excess profits	3.2b	$erpsf = rpsf - \overline{rpsf}$
Real price for producers	3.1c	$rpsf = pf + esf - psf$
Price	3.5a	$\Delta pf = 0.034 + (\Delta pdf - \Delta edf) - 2.523\Delta qf + 1.259\Delta yf + \varepsilon_{f3}$
		<u>Beverages</u>
Production	3.1a	$\Delta qb = \Delta qcb + \Delta ub$
Potential production	3.2a	$\Delta qcb = 0.012 + 0.080 cepsb + \varepsilon_{b1}$
		$\varepsilon_{b1} = -0.322\varepsilon_{b1-1} + \omega_{b1}$
Utilization	3.1b	$\Delta ub = -0.001 + 0.161\Delta rpsb_{-1} + \varepsilon_{b2}$
		$\varepsilon_{b2} = -0.535\varepsilon_{b2-1} + \omega_{b2}$
Average excess profits		$cespb = (epsb_{-1} + epsb_{-2} + epsb_{-3} + epsb_{-4}\ epsb_{-5} + epsb_{-6} + epsb_{-7})/7$
Excess profits	3.2b	$erpsb = rpsb - \overline{rpsb}$
Real price for producers	3.1c	$rpsb = pb + esb - psb$
Price	3.5a	$\Delta pb = -0.089 + (\Delta pdb - \Delta edb) - 1.318\Delta qb + 1.570\Delta yb + 0.240 db_1 + 0.705 d + \varepsilon_{b3}$
		<u>Agricultural raw materials</u>
Potential production	3.2a	$\Delta qca = 0.029 - 0.001t + 0.011 cepsa + \varepsilon_{a1}$
Average excess profits		$cespa = (espa_{-1} + espa_{-2} + espa_{-3} + espa_{-4})/4$
Excess profits	3.2b	$erpsa = rpsa - \overline{rpsa}$
Real price for producers	3.1c	$rpsa = pa + esa - psa$
Price	3.5b	$\Delta pa = -0.047 + 0.663(\Delta psa - \Delta esa) + 0.337(\Delta pda - \Delta eda) + 3.404\Delta ya - 6.582\Delta qca + \varepsilon_{a2}$
		<u>Metals</u>
Potential production	3.2a	$\Delta qcm = 0.013 + 0.169 cepsm + \varepsilon_{m1}$
Average excess profits		$cespm = (epsm_{-1} + epsm_{-2} + epsm_{-3} + epsm_{-4} + epsm_{-5} + epsm_{-6} + epsm_{-7})/7$
Excess profits	3.2b	$erpsm = rpsm - \overline{rpsm}$
Real price for producers	3.1c	$rpsm = pm + esm - psm$
Price	3.5b	$\Delta pm = -0.057 + 0.582(\Delta psm - \Delta esm) + 0.418(\Delta pdm - \Delta edm) + 2.594\Delta ym - 2.132\Delta qcm + \varepsilon_{m2}$

1/ The aggregation of group price indices is "arithmetic" for the logarithms of prices, or "geometric" for their antilogarithms; this methodology is not the same as the methodology ("arithmetic" for the antilogarithms) used to derive the current index. In addition, the current index is based on 1968-70; the index used in this paper is based on 1979-81.

Table 7. Dynamic Simulation of Prices

Commodity groups	Overall commodity	Food	Beverages	Agricultural raw materials	Metals
Sample period	1969-82	1965-82	1969-82	1965-82	1968-82
Correlation coefficient between actual and simulated value					
Prices	0.988	0.976	0.972	0.954	0.945
Rate of change in prices	0.945	0.825	0.827	0.862	0.838
Root mean squared error compared with standard deviation of actual values (in parentheses)					
Prices	0.088 (0.491)	0.132 (0.467)	0.167 (0.583)	0.139 (0.436)	0.112 (0.308)
Rate of change in prices	0.053 (0.161)	0.113 (0.201)	0.147 (0.268)	0.091 (0.185)	0.085 (0.167)

the same as the actual historical prices. The results are summarized in Table 8. In (2a) the extent of the impacts of the supply shocks on overall commodity prices is assessed. As already indicated, supply shocks are incorporated only for food and beverages. In this paper the impacts of the supply shocks are estimated by equation 3.1b:

$$(3.1b) \qquad \Delta u = \alpha_0 + \alpha_2 \Delta rps_{-1} + ss$$

which may be written with a stochastic error term (e) as follows:

$$(3.1b)' \qquad \Delta u = \alpha_0 + \alpha_2 \Delta rps_{-1} + ss + e$$

Both 'ss' and 'e' are not observed. It is, however, noted that 'ss' and 'e', should not be correlated with rps_{-1}; regressing Δu on Δrps_{-1} is, therefore, statistically valid. The impacts of supply shocks are estimated by

$$(3.6) \qquad ss + e = \Delta u - \alpha_0 - \alpha_2 rps_{-1}$$

which may be a reasonable approximation of the impacts of supply shocks on the utilization of potential production. The simulation results reported in (2a) are based on supply shocks equal to their mean values during the simulation period (1969-82) for both food and beverages.

In (2b), both domestic prices and exchange rates of exporting and importing countries are assumed to have been fully stable, while in (2b.i) and (2b.ii), domestic prices and exchange rates are stabilized alternately. In (c), industrial production is assumed to have been fully stable. Finally, in (2d), all of these variables (2a) through (2c) are assumed to have been stabilized around their long-term trends. The results show that the elimination of major sources of price instability (supply shocks, domestic prices and exchange rates in trading countries, and industrial production) reduces the commodity price variability by 40 percent (from 0.420 to 0.254) for levels and by 60 percent (from 0.161 to 0.064) for rates of change. The results also show that the two dominant sources of the variability of U.S. dollar prices have been fluctuations of industrial production and exchange rates. Stabilization of industrial production would have reduced the standard deviation of changes in price by 23 percent (from 0.161 to 0.124) and that of prices by 10 percent (from 0.420 to 0.379). Stabilization of exchange rates would have reduced the standard deviation of changes in price by 12 percent (from 0.161 to 0.141) and that of prices by 18 percent (from 0.420 to 0.346).

Table 8. Sources of Commodity Price Instability

	Sample Period	Price 1/		Changes in price	
		Standard deviation	Deviation from (1)	Standard deviation	Deviation from (1)
Actual	1969-82	0.420		0.161	
Simulated based on					
(1) Historical values of exogenous variables	1969-82	0.420		0.161	
(2) The following exogenous variables fully stabilized					
(2a) Supply shocks	1969-82	0.393	-0.027	0.141	-0.020
(2b) Domestic prices and exchange rates	1969-82	0.324	-0.096	0.123	-0.038
(2b.i) Domestic prices	1969-82	0.414	-0.006	0.150	-0.011
(2b.ii) Exchange rates	1969-82	0.346	-0.074	0.141	-0.020
(2c) Industrial production	1969-82	0.379	-0.041	0.124	-0.037
(2d) All variables (2a)-(2c)	1969-82	0.254	-0.166	0.064	-0.097

1/ The standard deviation of the error terms estimated by regressing the logarithms of prices on the linear time trend.

The simulations that provided the results summarized in Table 8 may be viewed from a different angle. Table 9 shows how the historical paths of prices during the two recent commodity price cycles (1973-77 and 1979-83) would have changed under alternative scenarios. 1/ The results indicate the contributions made by the various factors. First, supply shocks reinforced the demand-side factors during all the phases of the two cycles; without supply shocks, the price fluctuations during the two cycles would have been significantly smaller. Supply shocks reinforced demand-side factors particularly during 1973-74, 1976-77, and 1981-82. Second, the 1975 decline in prices was largely a result of the decline in industrial production; without the decline, prices would have increased. Third, the 1981-82 decline in prices can be attributed to both the appreciation of the U.S. dollar exchange rate and the decline in industrial production, with the former playing a larger role than the latter.

3. Simulation of supply-price dynamics

In the model, an increase in domestic prices or exchange rates (nominal or real) does not trigger an interaction between supplies and commodity prices; domestic inflation or a change in real exchange rates (exchange rates deflated by domestic prices) is transmitted to commodity prices instantaneously and fully without affecting real prices of commodities for producers, whereas a change in nominal exchange rates accompanied by no change in real exchange rates does not affect commodity prices.

The dynamic interaction between supplies and prices, however, is triggered by any shocks that affect real prices of commodities for producers. For example, an increase in demand for commodities resulting from an increase in economic activity, other things being equal, results in an increase in real prices of commodities and, through the effect of such increases on expected future prices, triggers increases in production in subsequent years; these increases in production in turn put downward pressure on prices which reduces production in subsequent years, triggering another round of price increases. In such a situation, therefore, a temporary increase in demand leads to long-lasting changes in commodity prices. To simulate this supply-price dynamic, the following experiment is conducted. Prices are simulated for the all the commodities combined, as well as for the four standard groups: food, beverages, agricultural raw materials, and metals; industrial production is assumed to be 5 percent higher than the actual historical values for 1970, but the same as historical values for all other years. The simulated prices are compared with those resulting from historical values of industrial production.

1/ The analysis in this subsection is confined to the sample period ended 1982; the analysis of the price changes in 1983-84 is presented later in this subsection.

Table 9. Sources of Commodity Price Fluctuations

	The 1973-77 price cycle			The 1979-83 price cycle 1/	
	Increases 1973-74	Decreases 1975	Recovery 1976-77	Increases 1979-80	Decreases 1981-82
	(Cumulative percentage changes)				
Actual	63	-19	33	23	-28
Simulated on the basis of:					
(1) Historical values of exogenous variables	63	-19	33	23	-28
(2) The following exogenous variables fully stabilized					
(2a) Supply shocks	56	-16	15	21	-20
(2b) Domestic prices and exchange rates	43	-19	39	17	-4
(2b.i) Domestic prices	48	-18	34	18	-31
(2b.ii) Exchange rates	57	-19	39	-22	-1
(2c) Industrial production	61	6	25	27	-12
(2d) All variables (2a)-(2c)	39	7	12	17	20

1/ The 1983-84 recovery is analyzed later in this section.

The difference between the two paths of price series suggest how prices intereact with supply (Table 10). On the basis of the impacts in the first year, the elasticities ranging from 1.3 for food and 3.4 for agricultural raw materials confirm the results reported in Table 5. These positive impacts of an increase in industrial production on commodity prices are partly eroded in subsequent years. For food and beverages, high real prices trigger increases in the utilization of potential production in the following year. At the same time, for all commodity groups, potential production begins to respond to the high prices. The resulting price decreases peak three to four years after the initial shock for food and agricultural raw materials, and seven years after for beverages and metals. The simulation results suggest that the amplitudes of price oscillations are larger for agricultural raw materials and metals than for food and beverages. In particular, for metals, the amplitude of the oscillation is so large that a substantial initial price increase resulting from a shock can be completely eroded in seven years. Overall, the elasticity is reduced to 0.3 in 12 years; comparable long-run elasticities range from -1.0 for metals to 1.4 for agricultural raw materials.

The simulation results summarized in Tables 8, 9 and 10 confirm the authors' earlier analysis (Chu and Morrison (1984)) of the three demand-side factors underlying commodity price fluctuations since the early 1970s--fluctuations of economic activity in industrial countries, world inflation, and exchange rates. Unlike the eariler study, however, the present study shows how supply-price dynamics could intensify or reduce commodity price fluctuations by increasing (or decreasing) utilization in the short run and potential production in the medium run following initial increases (or decreases) in commodity prices due to demand shifts. It should also be noted that as reported in Table 10, the supply responses subsequent to an initial demand shock appear to peak around the sixth year following the shock. It is therefore quite plausible that the 1973-74 commodity price boom might have softenend somewhat another demand-induced commodity price boom about six years later during 1979-80.

4. Simulation of the 1983-84 commodity price recovery

In this subsection, the model is used to simulate the 1983-84 commodity price recovery. For this simulation, the actual values for some exogenous variables (domestic prices, exchange rates, and industrial production) for 1983 and 1984 are available. Production estimates for food and beverages are also available. Commodity price increases for 1983 and 1984 can be simulated on the basis of these exogenous variables and compared with the actual increases for 1983 and 1984. In Table 11, the simulated overall price changes for 1983 and 1984 are compared with actual price changes in Part A; the assumptions underlying the simulations are summarized in Part B. The overall price changes are simulated by aggregating simulated price changes for individual groups. The simulations of price increases for food, agricultural raw materials and metals are conducted in a straightforward manner. For beverages,

Table 10. Effects of a Demand Shock on Prices

Years	Overall	Food	Beverages	Agricultural raw materials	Metals
	Percent changes in prices				
	(Annual percentage changes in prices resulting from a 5 percent increase in industrial production)				
0	10.3	6.3	7.8	17.0	13.0
1	-1.0	-0.9	-1.8	-0.3	-0.7
2	-0.5	-0.2	0.2	-0.6	-1.3
3	-0.8	-0.5	-0.3	-0.9	-1.9
4	-1.0	-0.4	-0.3	-1.2	-2.3
5	-1.1	-0.4	-0.4	-1.1	-2.7
6	-1.1	-0.3	-0.5	-1.0	-2.9
7	-1.1	-0.3	-0.5	-1.0	-3.0
8	-0.9	-0.3	-0.5	-0.9	-2.2
9	-0.7	-0.3	-0.4	-0.8	-1.4
10	-0.4	-0.2	-0.4	-0.8	-0.5
11	-0.2	-0.2	-0.4	-0.7	0.2
12	-0.1	-0.2	-0.3	-0.6	0.9
	(Elasticity)				
Short-run:					
First year	2.0	1.3	1.6	3.4	2.6
First 2 years	1.8	1.1	1.2	3.3	2.5
Long-run:					
13 years	0.3	0.4	0.4	1.4	-1.0

Table 11. Simulation of the 1983-84 Commodity Price Recovery

(Annual percentage changes)

A. Overall commodity prices

	Actual	Simulated
1983	6	5
1984	1	2

B. Assumptions

	Commodity Production	Industrial Production	Domestic prices 1/ Exporting Countries	Domestic prices 1/ Importing Countries
1983				
Food	-3	2	-- 2/	-4
Beverages	10	3	-- 2/	-4
Agricultural raw materials	-- 2/	3	-4	-5
Metals	-- 2/	3	-7	-4
1984				
Food	5	6	-- 2/	-5
Beverages	-2	6	-- 2/	-4
Agricultural raw materials	-- 2/	6	1	-5
Metals	-- 2/	6	2	-4

1/ Adjusted for exchange rate changes.
2/ Not shown because they are not used as exogenous variables to simulate prices.

however, 1983-84 was a rather unusual period in that a significant increase in production was accompanied by a price increase. A number of explanations could be given. A major part of world supply of coffee--the dominant commodity in the beverage group--was under the control of the International Coffee Organization (ICO) in terms of an export quota arrangement. The ICO also strengthened the effectiveness of the export control scheme during 1983-84. The droughts in West Africa lowered the quality of robusta coffee produced in that region, reducing the supplies of quality coffee of that brand. The impacts of these developments, however, are difficult to quantify. It should also be noted that the recovery of about 8 percent for beverage production in 1983-84 followed a 13 percent decline in 1982. As the two episodes in 1974 and 1977 suggest, the 8 percent production recovery, following a major production failure (-14 percent), probably was not sufficient to reverse the upward pressure on prices. 1/ The simulated price increase reported for beverages is therefore obtained by utilizing the coefficient estimated for the dummy variable to explain the price increase in 1974 in the presence of a production recovery. 2/

The simulations slightly underpredict the price increases for 1983, but slightly overpredict the price increases for 1984. The simulations, however, correctly predict the deceleration in the overall commodity price recovery in 1984.

The model may be used to isolate the effects of some of the above factors. For example, the following scenarios are examined:

(i) Had food production remained the same in 1983 as in 1982, instead of declining by 3 percent, food prices would have remained the same as in 1982, rather than having increased by 8 percent. An 8 percentage point decline in food prices in 1983 would have lowered the rate of increase in overall commodity prices in 1983 by 3 percentage points. To what extent were the declines of food production in 1983 and of beverage production in 1982 attributable to the decline of real food prices in 1982 and of real beverage prices in 1981? Real food prices declined by 6 percent in 1982; real beverage prices by 32 percent in 1981. Estimated equation (3.1b) for the change in utilization of potential production suggests the elasticity of utilization of 0.04 with respect to real prices for

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1/ To a large extent, the 8 percent increase in beverage prices in 1983 is also attributable to sharp increases (22 percent and 20 percent, respectively) in cocoa and tea prices; coffee prices increased by only 3 percent. The sharp increases in cocoa and tea prices were largely related to poor crops.

2/ See the footnote on page 17. The simulation is based on 1 for the first of the two dummy variables in equation (3.5a) as one of the predetermined variables. This procedure is admittedly arbitrary and reflects the authors' judgment of the sequence of the events that led to the price increase. In 1983, unlike in 1974, fairly large coffee stocks existed, but, as mentioned earlier, export supplies were under the control of the ICO.

food and 0.16 for beverages. Therefore, although the impact of the decrease in real prices on food production in 1983 was negligable, the impact for beverages in 1982 was perhaps substantial.

(ii) In 1982, world metal production declined by 6 percent; this decline in production suggests a significant increase in the under-utilization of productive capacity of metals in 1982. Perhaps the excess capacity of metal production acted to cushion against any increase in metal prices. In this connection, it should be noted that potential production data used in this study are estimated from the trend-through-peak method. 1/ In view of the nature of this method, potential production for agricultural raw materials and metals during the late 1970s and the early 1980s could have been underestimated. In such a case, the impacts of excess capacity on agricultural raw materials and metal prices could have been larger. It should also be noted that the model suggests 3 percent increases in potential production of food and beverages in 1983. This projection reflects excess profits estimated for the food and beverage sectors in recent years. Had it not been for this increase in potential production, the impacts of the adverse weather in 1982-83 on food and beverage prices could have been larger. 2/

(iii) Had industrial production of European countries increased by 6 percent, rather than by 2 percent in 1983-84, the rate of increase in overall commodity prices could have been raised by 5 percentage points. This rather large simulated impact on commodity prices is explained by the fact that Europe accounts for about one-half of total world imports of non-oil primary commodities.

In 1983-84, domestic prices in both exporting and importing countries generally declined after the exchange rate adjustments vis-a-vis the dollar, reflecting both appreciation of the dollar and possibly the efforts of some primary exporting developing countries to depreciate their currencies in real terms. In addition, industrial production grew only modestly, in comparison with 1976-77. 3/ All these factors, except for the supply shocks, appear to have kept the recovery of primary commodity prices fairly modest in 1983-84.

1/ See Annex for a description of the method.

2/ This possibility is not indicated formally by the model. However, a lower world-wide capacity to produce food and beverages would have resulted in a lower actual production because of adverse weather conditions. These conditions would have led to larger price increases for food and beverages.

3/ In 1983, aggregate industrial production of importing countries was about 2-3 percent higher than in 1982, while it was 7-8 percent higher in 1976 than in 1982. This low increase in industrial production occurred, although the quarterly index of aggregate industrial production increased in 1983 as rapidly as in 1976-77, because the trough occured toward the end of 1982, while it occurred earlier in 1975.

Supply-price dynamics also provide a linkage between current prices and future prices through the effects of current excess profits on future changes in potential production. The low commodity prices and consequential negative excess profits during 1981-82 suggest possible deceleration in the growth of potential production of commodities during 1986-87 in the case of food and beverages and 1988-89 in the case of agricultural raw materials and metals. If an expansionary phase of the world economic cycles coincides with either of these periods, commodity prices could increase sharply.

VI. Summary and Conclusions

In this paper, an econometric model of world non-oil primary commodity markets focusing on supply-price dynamics has been presented. The model incorporates supply-side and demand-side factors, as well as the interactions between supplies and prices over the short term and medium term. The model decomposes production of commodities into potential production and utilization rate; potential production is shown to respond to medium-term fluctuations of price; utilization rate to short-run fluctuations. The model is used to analyze and estimate the sources of commodity price instability; it is also used to analyze the slow pace of the 1983-84 recovery of commodity prices. The main conclusions may be summarized as follows:

The analysis quantifies the impact of supply-price dynamics on fluctuations of commodity prices. It shows that most of the price increase due to a demand shock could be eroded in the long run. For example, the elasticity of commodity prices with respect to industrial production changes from about 2.0 in the short run to 0.3 in the long run. This erosion results from supply responses to the initial price increase. The model traces historical movements of commodity prices fairly closely, and confirms the authors' earlier findings (Chu and Morrison (1984)) that industrial production and exchange rate fluctuations were major factors underlying commodity price flucuations since the early 1970s. The simulations based on the model also show that short-run supply shocks reinforced demand-side factors during the last two commodity price cycles (1972-77 and 1979-83), which also confirms the earlier findings. Unlike the earlier study, however, the present analysis estimates the extent of the cost-push channel through which inflation in exporting countries that is transmitted to world commodity prices. The study shows that for agricultural raw materials and metals, the cost-push channel was more important than the substitution channel in the short run.

The analysis also shows that low world inflation (after adjusting for exchange rate changes) and a low pace of recovery in European economies were important reasons for the relatively slow recovery of commodity prices after the 1981-82 recession. The model suggests that had industrial production of European countries increased by 6 percent, rather than by 2 percent in 1983-84, the recovery in overall commodity prices could have been 5 percentage points higher.

This Annex discusses a number of topics not covered adequately in the main text. Section 1 of the Annex presents an overview of world trade in non-oil primary commodities; Section 2 discusses the statistical data used in the paper; Section 3 explains the methodology used to estimate potential production; and Section 4 discusses details of the statistics showing the goodness of fit for the model.

1. World trade in non-oil primary commodities

The share of primary commodities in total merchandise exports remained at about 30 percent during 1979-81, the same as during 1968-70. The share of non-oil primary commodities, however, declined from 23 percent during 1968-70 to 16 percent during 1979-81. Food items account for about half of the total value of non-oil commodity trade, while agricultural raw materials and metals accounts for 21 percent each and beverages for the remainder (7 percent) (Table 1). Industrial countries dominate both exports and imports of food, agricultural raw materials, and metals, accounting for about 70 percent of exports and 70-90 percent of imports; for beverages, developing countries account for the bulk (79 percent) of exports, while industrial countries account for the bulk of imports (88 percent). Among industrial countries, the United States and some of the smaller countries outside Europe and Japan are major exporters of food, agricultural raw materials, and metals, whereas Europe, Japan, and the United States are major importers. The United States and Europe are also major importers of beverages.

2. Statistical data

Statistical data used in the study are derived as follows:

a. Commodity prices

The 40 representative international price series of 34 primary commodities are included with the weights as shown in Table 2. The weights reflect the world export values of these commodities during 1979-81. 1/ The individual prices are obtained from the *International Financial Statistics*.

b. Production

Annual production series from the World Bank data bank are used. The production series are available for the commodities identified in Table 2 except for the commodities whose weights are in parentheses. In aggregation, the normalized weights for the subset of the sample commodities are used. Potential production series are derived on the basis of production series (Section 3).

1/ The commodity coverage and the weights of the index used in this study are somewhat different from those of the current Fund index.

Table 1. World Trade in Non-Oil Primary Commodities (1979-81 average)

	Trade value		Exports							Imports						
	In US$ billion	Share	World	Industrial countries					Others	World	Industrial countries					Others
				Total	U.S.	Europe	Japan	Others			Total	U.S.	Europe	Japan	Others	
Total non-oil	257	100	100	68	19	33	1	15	32	100	79	12	51	14	2	21
Food	130	51	100	76	25	39	1	11	24	100	72	8	50	11	3	28
Beverages	18	7	100	21	9	12	0	1	79	100	88	24	55	5	4	12
Agricultural raw materials	54	21	100	66	16	29	1	20	34	100	81	11	48	19	3	19
Metals	54	21	100	67	11	33	1	22	33	100	89	16	51	19	3	11

Table 2. Weights Used to Aggregate Commodity Prices and Production

	Weights 1/
Total non-oil commodities	100.0
Food	42.7
Edible oils and seeds	11.8
Soybeans	4.8
Soybean cake	2.8
Soybean oil	1.3
Palm oil	1.2
Coconut oil	0.6
Groundnut oil	0.3
Groundnut cake	0.1
Copra	0.1
Fishmeal	0.6
Cereals	20.7
Wheat	10.0
Rice	3.2
Maize	7.5
Sugar	3.2
(U.S.)	1.1
(Free Market)	1.6
(EEC)	0.5
Meat	6.4
(Beef)	5.4
(Lamb)	0.9
Bananas	(0.9)
Beverages and tobacco	14.2
Beverages	11.7
Coffee	7.4
(Robusta)	3.4
(Other milds)	4.0
Cocoa	3.1
Tea	1.3
Tobacco	2.5
Agricultural raw materials	20.9
Fibers	6.4
Cotton	3.9
Medium	3.4
Long	0.5
Wool	2.4
Fine	1.5
Coarse	1.0
Hide	(1.2)
Nautral rubber	2.6
Logs and timber	(10.5)
Jute	(0.1)
Sisal	(0.1)
Metals and phosphate rock	22.0
Metals	20.8
Iron ore	4.1
Copper	5.8
Nickel	1.8
Aluminum	4.5
Zinc	1.4
Tin	2.1
Lead	1.1
Phosphate rock	(1.2)

1/ For aggregate commodity prices; for aggregate production series, commodities whose weights are in parentheses are excluded.

c. Economic activity, world inflation, and exchange rates

The series used for the variables are:

(i) economic activity: industrial production;

(ii) world inflation: exporting and importing countries' wholesale price indices (WPI's) or consumer price indices (if WPI's are not available).

To simplify aggregation, major exporters and importers (accounting for at least two percent of world total) for each of the four commodity groups (food, beverages, agricultural raw materials, and metals) are included. For each of the variables (industrial production in importing countries, domestic prices and exchange rates vis-a-vis the U.S. dollar in exporting and importing countries) data for the individual countries are aggregated with the appropriate weights for the sample countries. The structure of weights is summarized in Table 3.

3. Potential production

The methodology utilized to derive potential production is the trend-through-peak method used by Klein and Summers (1966). In the absence of relevant statistical data, more rigorous methods such as those employed by Artus (1977) could not be used. 1/ In addition to the data problem and the usual problems associated with the trend-through-peak method, applying the potential production idea to world primary commodity production gives rise to a number of conceptual problems. It may not be meaningful to define potential production for a single commodity in some cases. For example, a certain area of land may be used by two competing crops alternately (e.g., jute and rice). Therefore, connecting peaks may yield overestimated potential production series for a group of commodities. In these cases, more relevant potential production series may be derived only on the basis of aggregate production series of two competing crops, rather than on the basis of only one crop. Deriving potential production series on the basis of aggregate world production series could also yield biased results unless production peaks coincide in their timing in all producing countries. There is also the question of whether low production due to adverse weather should be regarded as underutilization of potential production or low potential production.

Although the concept "potential production" as used in this paper needs refinement and improvement, it represents a reasonable approximation for analyzing the supply-price dynamics.

1/ See Christiano (1981) for a survey of measures of potential production and capacity utilization for the manufacturing sector or aggregate production.

Table 3. Shares of Exports and Imports

	Exporters							Importers						
	World	Industrial countries					Others	World	Industrial countries					Others
		Total	U.S.	Europe	Japan	Others			Total	U.S.	Europe	Japan	Others	
	(With total trade value = 100)													
Food	86	65	21	33	0	11	21	79	57	6	39	9	3	22
Beverages	84	18	8	10	0	0	66	90	79	22	49	4	4	11
Agricultural raw materials	77	51	12	22	0	17	26	90	73	10	43	17	3	17
Metals	84	56	9	28	0	19	28	91	81	15	46	17	3	18
	(With trade value of sample countries = 100)													
Food	100	88	34	16	0	38	12	100	97	11	67	16	2	28
Beverages	100	17	9	7	0	0	83	100	100	29	62	7	2	0
Agricultural raw materials	100	92	29	29	0	35	8	100	91	13	52	23	2	9
Metals	100	75	15	25	2	32	25	100	100	19	56	22	3	0

The series of potential production for each of the four commodity groups is derived as follows:

(i) For each commodity, for which relevant production series is available, the years in which world production reached medium-term peaks are identified. Of these years, those years in which production peaks occurred on account of unusually favorable production conditions (e.g., good weather) are excluded. For the remaining years, changes in actual production are compared with changes in prices in the current or immediately preceding years. These comparisons are useful to ensure that the years chosen are the years during which high demand for commodities led to full or near-full utilization of potential production.

(ii) For the beginning and the ending years, judgments are made on possible behavior of potential production for each commodity.

(iii) The potential production series thus derived for the sample commodities are normalized to 1979-81(=100) and are aggregated on the basis of the weights shown in Table 2 of this annex.

4. The model simulation: goodness of fit

In the main text of this paper (Section V), the model's capability to trace the historical movements of actual overall prices is reported. In Table 4 of this annex, more detailed results are shown. The model traces both price levels and changes in prices fairly closely for all commodity groups. It also traces the movements of real prices, average excess profits, and potential production fairly well, except for the average excess profits for agricultural raw materials. The poor performance of the model to trace the movements of average excess profits, however, does not yield equally poor results for potential production because for agricultural raw materials, time trend is a more important explanatory variable for changes in potential production.

Table 4. Correlation Between Actual and Simulated Endogenous Variables

Variables	Sample Period	Symbols	Food	Beverages	Agricultural raw materials	Metals
Levels	1969-82					
Price		P_t	0.963	0.972	0.959	0.942
Real price for producers		rps_t	0.621	0.888	0.699	0.853
Average excess profits		$ceps_t$	0.546	0.929	0.049	0.947
Potential production		qc_t	0.999	0.894	0.814	0.974
Rates of change	1969-82					
Price		Δp_t	0.836	0.827	0.869	0.845
Real price for producers		Δrps_t	0.675	0.824	0.834	0.766
Potential production		Δqc_t	0.497	0.762	0.996	0.711

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