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Intercommodity Price Transmittal

Analysis of Food Markets in Ghana

Harold Alderman

This dynamic model of price integration indicates functional — if not perfect — efficiency in Ghana's coarse grain markets.

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This paper — a product of the Agriculture Operations Division, Western Africa Department, and the Agricultural Policies Division, Agriculture and Rural Development Department — is part of a larger departmental study of food security in Ghana. Copies of the paper are available free from the World Bank, 1818 H Street NW, Washington, DC 20433. Please contact Cicely Spooner, room N8-039, extension 30464, or by electronic mail (April 1992, 36 pages).

Alderman expands on a dynamic model of market integration, first introduced by Ravallion (1986) to Ghana's principal maize markets, to investigate how information is transmitted across commodities. He investigates one property of an efficient market: the full use of available information.

Studies of spatial price integration simultaneously investigate the flow of information and commodities, but it is often difficult to distinguish between the two. A low correlation of prices between two markets may indicate either a poor flow of information or economic inefficiency, for example — but could also indicate competitive trade and linked markets that are seasonally separated because of high transport costs.

So Alderman also investigates the flow of information within a single spatial market and the relationship between prices in spatially separate markets.

He studies intercommodity price transmittal from two perspectives. First, he asks whether the government can concentrate on a single commodity price, yet achieve price policy objectives in a broader arena. This is important in Ghana because no single commodity dominates consumers' food budgets, although for administrative and logistical reasons, direct intervention in all commodity markets is not feasible. He finds that price movements for the main cereal consumed in the country (maize) are fully transmitted to other grains and to other regions. This simplifies any stabilization programs. (However, it takes three months for the price shock to be fully transmitted. In the long run, this indicates market integration, but it is puzzling that it takes so long to move commodities between markets.)

Second, he investigates the working of commodity markets in developing countries. He notes imperfections in the way markets process information: the lagged price of maize conveys information that is not contained in the past price of sorghum or millet.

There are several possible explanations for this market inefficiency. For example, traders may set prices for other coarse grains in response to information about maize prices — requiring supply changes (especially storage buildup and drawdown) to bring markets into equilibrium. Another possibility is that some traders may not deal in all grains and may therefore have different costs for acquiring information — especially for sorghum, which is both eaten and used for making beer. Brewers, most of whom operate on a small scale, may trade and store only sorghum, which may thus be a conceptually separate (although physically contiguous) market. But even for speculative markets in industrial countries, in which information is generally available electronically and trade rarely requires the physical exchange of goods, perfect price transmittal is often rejected.

In short, from a practical viewpoint, Alderman's dynamic model of price integration indicates functional — if not perfect — efficiency in Ghana's coarse grain markets.

Intercommodity Price Transmittal:
Analysis of Food Markets in Ghana

by

Harold Alderman*

Table of Contents

I.	Introduction	1
II.	Methodology for Analysis of Market Integration	4
	Theoretical Considerations	4
	An Interregional Two Commodity Model	7
	Cointegration Models	12
III.	Data and Results	15
	Results of the Dynamic Interregional Model	19
	Results of Tests of Integration and Cointegration	27
IV.	Conclusion	31
References		34

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INTERCOMMODITY PRICE TRANSMITTAL: ANALYSIS OF FOOD MARKETS IN GHANA

I. INTRODUCTION

Since establishing a stable macroeconomic environment for long run development, the government of Ghana has explored a number of specific policies aimed at stabilizing food prices between seasons and across years. These policies have ranged from income support and employment generation programs to improving marketing infrastructure. Options under consideration have also included the possiblity of increase government involvement in inter- and intra-year storage; in recent years government held storage capacity has been increased despite the fact that there is not yet a clearly articulated policy on the objectives of such storage. The implementation of storage and other stabilization policies depends, in part, on the existing efficiency of trader operations.

Similarly, the effectiveness of other possible interventions to guarantee food security that do not involve the government's direct handling of grain also depends on knowing which market channels operate effectively. For example, the potential for cash grants and food for work programs in districts with temporary production shortfalls to stabilize consumption is enhanced when markets in areas with low or variable levels of food consumption are linked to surplus regions via effective market channels.

As part of such policy oriented analysis, a number of studies of markets in Ghana (Asante et al.) as well as other developing countries have analyzed the relationship of the price of a single commodity in various markets. With proper caveats, such studies are used to make inferences on the spatial flow of information and commodities. However, given that households in the regions of

Ghana that are food insecure by a number of measures are in the northern savannah regions where sorghum and millet are primarily consumed (Alderman 1990) there is a need to know how the markets for these commodities link with the markets for maize, on which government policy is likely to focus.

The current study - one component of a larger series of studies on food security in Ghana- begins with an application of a dynamic model of market integration first introduced by Ravallion (1986) to principal maize markets in Ghana. The main interest of the study, however, is to expand upon the model in order to investigate the transmittal of information across commodities. We investigate one property of an efficient market, the full utilization of available information. While studies of spatial price integration simultaneously investigate the flow of information and commodities, it is often difficult to distinguish between the two. For example, while a low correlation of prices between two markets may indicate either poor flow of information or economic inefficiency, the observation may also be indicative of competitive trade and linked markets which are seasonally separated due to high transport costs (Timmer 1974).

For this reason the current study also presents an investigation of the flow of information within a single spatial market. This allows a test of the principle that if a market is efficient with respect to the information available, then the information conveyed by the price of commodity j in period t will not improve the prediction of the price of commodity i in period t+1 over the information already conveyed in the price of commodity i in period t. This property has been studied mainly in regards to capital markets (Malkiel), but Granger and Escribano's study of speculative prices for silver and gold acknowledges that the concept is also valid for commodities that are close substitutes.

Our purpose, however, is not solely to study the efficiency of markets. The results can be considered in the context of commodity price stabilization, using either trade or storage policies. While storage remains an expensive means to achieve a moderate amount of stabilization (Pinckney, Siamwalla), implementation of such policies is made easier to the degree that internal markets are integrated.[1] Similarly, if price movements are efficiently transmitted across commodities, stabilization policies can reduce the management burden by concentrating on one commodity. Moreover, as mentioned, since ecological conditions often dictate that regions of greatest food deficits consume different staple crops than those produced in surplus regions, even when stabilization programs are not attempted, governments may be interested in knowing the relationship of price movements of the surplus commodity and the staples in the deficit region. The results below are an empirical illustration of such price transmittal.

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[1] To a fair degree, also, such an approach to stabilization implies that internal markets are not fully integrated with external markets.

II. METHODOLOGY FOR ANALYSIS OF MARKET INTEGRATION

THEORETICAL CONSIDERATIONS

As mentioned, the analysis proceeds in three distinct stages. First, we apply a standard one commodity model of price transmittal to a West African setting. This allows for verification of earlier results of market efficiency presented in Ravallion (1986). Second, we use the same structure to investigate price transmittal across commodities. To a degree, this application is primarily statistical; theory does not give an unambiguous expectation for the magnitude the parameters of the model. Nevertheless, as discussed below, theory does indicate that the model is appropriate and day to day policy concerns indicate that it may be useful. Third, we apply a separate set of analyses, consistent with the former, which allow for testing hypotheses of information flows which are only meaningful in a multicommodity framework.

While this study does not aim to modify the basic theory and, hence, aims for brevity in this section, a few points need be addressed to justify the issues introduced and the approach followed. In particular, before laying out a general model of market integration one needs to address both the relationship that would exist across commodities and the potential insights that can be gained by broadening the core model to a multicommodity framework. In doing so, we also reiterate some of the well known reasons for considering a dynamic structure (Hendry, Pagan and Sargan).

Ravallion (1986) as well as Faminow and Benson, attribute the underlying basis of most models of spatial price integration to Takayama and Judge. Takayama and Judge lay out a set of optimization models to prove that when trade takes place, regional prices will differ by the transport cost. When the optimal amount of trade is zero, than the difference in price is less than the transport cost. Furthermore, if supply or demand conditions in the two markets change, it is possible that trade can shift so that the price differential is again the transport cost, but with the sign reversed.[2]

As this results holds in a multiproduct as well a single product context, a change in the price of one good, including a non-tradeable good, can change local demand such that the spatial price differential of another commodity rises to or declines from a point of equivalence to the transport cost.

This result, however, does not provide an indication of the speed at which prices adjust to shocks. Intertemporal demand theory recognizes partial adjustment in a variety of models, including those which consider habit formation, stock adjustment, and delays in processing new price information (Deaton and Muellbauer, Deaton). Similarly, analysis of agricultural production virtually always is based on lagged response to price information. Moreover, if supply is taken in the broader context of stock build-up and draw-down as well as production, one can also consider the speed at which traders and other suppliers to the markets react to price information (including overreaction to such information in the short run as indicated in Ravallion, 1987). It is this

[2] These points can be illustrated graphically with a standard back to back pair of supply and demand curves and a transport wedge.

context that provides the underlying basis for most market integration studies, in particular, Ravallion's (1986) dynamic application.

While the advantage of a dynamic model pertains to any spatial models of market integration, even those which consider a single commodity, the introduction of the speculative nature of trade and storage into a price formation model offers additional advantages in a multi-commodity model. In particular, it provides the basis for the test of the efficiency of information flows referred to in the introduction. Appeal to basic demand theory should be sufficient to indicate that prices of supplements and complements enter into the formation of current prices.[3] This, however, pertains to equilibrium values and does not say how markets forecast changes in prices. If a market is efficient with respect to some information set ϕ then it is impossible to make economic profits by trading on the basis of ϕ. Past prices are clearly a plausible candidate for ϕ. As such, changes in prices would be white noise; tomorrow's price change would reflect tomorrow's news but current information would be fully incorporated in today's price.[4] If prices of a second commodity improve the forecast of the first then they clearly provide news today and the basis for economic profits. As such, one would expect that in an efficient market the second series would be redundant. Granger and Escribano state this hypothesis in terms of drift of price series and provide the basis for the cointegration model presented below.

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[3] Prices of crops which are complements or supplements in production also influence market clearing prices.

[4] This abstracts from any forecastable changes in risks and transaction costs (Granger and Escribano).

AN INTERREGIONAL TWO COMMODITY MODEL

Studies of market efficiency based on bivariate correlations are acknowledged as providing limited information (Harriss). The basic problem is that two functionally isolated markets can appear to be synchronized if prices in each are influenced by a third market or by a common factor. A number of methodological improvements in recent years have gone beyond detrending (Haugh) to analyze the information contained in market price movements. For example, Delgado offers a variance components model that allows for a joint test of seasonal differences in the price integration of markets, while Ravallion (1986) places the standard model of market integration into a dynamic context. Timmer (1987) as well as Heytens offer modifications of Ravallion's model, providing intuitive interpretations on a subset of the model's parameters at a cost in terms of a simplification of the dynamic structure. Our main approach will follow from Ravallion's (1986) and Timmer's (1987) methods.

The structure of Ravallion's approach is comparatively simple, although the estimation is econometrically sophisticated. He posits a central, or reference, market (denoted by subscript 1), the price in which is a function of prices in a number of n-1 other markets as well as seasonal or policy variables.

$$P_1 = f_1 (P_2, P_3, \dots P_n, X_1) \qquad (1)$$

Prices in the feeder markets are functions of prices in the central market as well as policy and seasonal factors.

$$P_i = f_i (P_1, X_i) \qquad (i=2, \dots, n) \qquad (2)$$

Ravallion (1986) recognizes that the formulation above is most suited to a radial market structure, although it is adaptable to alternative channels as well. In any case, the key innovation is not the model of price formation per se but the dynamic structure of the estimation, which is indicated in eq. (3) and (4).

$$P_{1t} = \sum_{j=1}^{l} \alpha_{1j} P_{1t-j} + \sum_{k=2}^{n} \sum_{j=0}^{l} \beta_{1j}^{k} P_{kt-j} + \gamma_1 X_{1t} + e_{1t} \qquad (3)$$

$$P_{it} = \sum_{j=1}^{l} \alpha_{ij} P_{it-j} + \sum_{j=0}^{l} \beta_{ij} P_{1t-j} + \gamma_i X_i + e_{it} \qquad (i=2,\dots,n) \qquad (4)$$

for $n \neq 1$ where k indicates markets; j indicates lags.

Ravallion (1986) concentrates on eq. (4), recognizing that in many circumstances eq. (3) will be underidentified. If $\beta_{ij} = 0$ for all values of j in eq. (4) then the ith market is segmented from the central market. On the other hand, if $\beta_{io} = 1$, then prices are immediately transmitted. Moreover, if markets are integrated in the long run, then $\Sigma\alpha_{ij} + \Sigma\beta_{ij} = 1$. There are, in addition, possibilities of short-run integration less immediate than instantaneous price transmittal that can be tested with this model. While simultaneous weather shocks could influence the apparent r^2 values of the estimates as well as lead to a spurious value for β_{io}, the other parameters are less susceptible to this particular problem that has been reported in the literature.

While this model allows one to test various hypothesis about market efficiency, it does not provide an esily accessible summary statistic about the degree of integration between polar cases. To deal with this issue, Timmer (1987) and Heytens make two modification of this model. First, they work in the logarithm of prices. This implies ad valorem marketing costs rather than a fee per quantity handled. This innovation is, however, not essential to their second modification which is the assumption of a single lag structure for price formation rather than the six lags that Ravallion uses. This simplifies subsequent interpretation since a little algebraic manipulation allows one to reformulate the model as:

$$\begin{aligned}(P_{it} - P_{it-1}) &= (\alpha_{i-1})\ (P_{it-1} - P_{1t-1}) + \beta_{io}(P_{1t} - P_{1t-1}) \\ &+ (\alpha_i + \beta_{io} + \beta_{i1} - 1)\ P_{1t-1} + \gamma X + \mu_{it}\end{aligned} \tag{5}$$

With this expression, one sees that the temporal change in a peripheral market is a function of the spatial price spread in the last period, the temporal change in the central, or reference, market, and the price level in the reference market in the last period. Again, seasonal and policy variables are included.[5] This equation can be further manipulated to derive

$$P_{it} = (1 + b_1)\ P_{it-1} + b_2\ (P_{1t} - P_{1t-1}) + (b_3 - b_1)\ P_{t-1} + \gamma X + \mu_{it} \tag{6}$$

where

$$b_1 = \alpha_{i-1},\ b_2 = \beta_{io},\ b_3 = \alpha_i + \beta_{io} + \beta_{i1} - 1$$

In long-run equilibrium conditions, $(P_{1t} - P_{1t-1}) = 0$. If one assumes also that $\gamma = 0$, then $(1 + b_1)$ and $(b_3 - b_1)$ are, respectively, the contribution of local and central market price history to current prices. If the markets are well integrated, the latter will have a comparatively strong influence on the local price level. Timmer suggests that the relative magnitude of the two

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[5] These are bivariate dummy variables. As such, it is useful to include an intercept as well. Recently, Sexton et al. have introduced a sweitching regression alternative to model the probability of market autarky.

influences can be indicated by their ratio. He defines this as the index of market connectedness (IMC) with values less than 1 as indicating short-run market integration.[6]

$$IMC = \frac{(1 + b_1)}{(b_3 - b_1)} \tag{7}$$

Clearly this index is useful for comparative purposes, although it is only approximate, not only due to the above-mentioned truncation of the lag structure but also as the vector of parameters denoted by γ may not be insignificant.

Timmer (1987) also argues that $\underline{b_2}$ is a measure of the degree to which changes in prices in the reference market are transmitted to other markets. This parameter is expected to be close to 1, although even if markets are perfectly integrated some difference from 1 could reflect a mixture of absolute and proportional marketing costs.

Both Heytens and Ravallion use these models to test for the existence of any seasonal patterns in market integration.[7] This is important as it is possible that in some seasons the cost of transport exceeds the difference in production or import prices between two markets. At such times, the price in one market could appear not to be linked with movements in the other.[8]

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[6] The choice of the cut-off is somewhat arbitrary although indicative.

[7] In addition, Ravallion tests for the existence of a specific famine year effect.

[8] One can consider this analogous to a situation in which world markets do not affect local prices of a small country when that country's market clearing price lies between import and export parity prices.

An important reinterpretation of the Ravallion model is found in Faminow and Benson. They build upon Hotelling's model of locational interdependence which can be considered as spatial oligopoly. In particular, they note that short run integration as defined by Ravallion may be generated by collusive base point pricing. However, a rejection of short run integration and acceptance of long run integration is compatible with a model of market competition.

Inference from such a model depends, in part, on the nature of the market structure. Ravallion assumes a radial market with few, if any, local market linkages; Faminow and Benson discuss markets in which agents are not located at a few points but are spatial disbursed. As discussed below, the spatial nature of the markets studied lend themselves to the Ravallion model employed. Moreover, if two regions or markets specialize in different commodities, so that the radial structure pertains to more than one commodity, the model discussed above can be adapted to a multicommodity framework. Tests for market segmentation in such a multicommodity framework would still be appropriate. Similarly, the IMC would be a rough measure of the local versus reference market influences, albeit the influence would work through the matrix of cross price responses. There is no particular reason, however, why the price transmittal would be exactly one for one from a particular commodity to another under either short or long run integration. Nevertheless, the magnitude of β_{i0} and $[\Sigma\alpha_{ij} + \Sigma\beta_{ij}]$ would still provide information that measures the net transmittal of shocks in one market to another.

Although cross price effects are generally not addressed in models of market integration they are explicitly recognized in general equilibrium and multi-market agricultural models. An understanding of the interactions of price policies in a multi-commodity environment can, for example, be gained from matrices of consumer and producer own- and cross-price responses. An illustration is found in Pinstrup-Andersen et al.. This particular application also indicates one limitation of the demand system approach; often the necessary cross-price matrix is difficult to obtain with precision.[9] One advantage of the two commodity autoregressive model is that it relies on less restrictive assumptions than many complete structural models. Therefore, it provides an alternative means of modelling interactions of price policies. Moreover, although such models require a reliable time series of price information, they do not require information often unavailable from developing countries, such as data on quantities demanded or supplied over time and regions.

CO-INTEGRATION MODELS

Ravallion (1986) indicates that under long-run integration, the model he presents is a member of the class of error correction models. These, in turn, are related to models of co-integration (Engle and Granger, Hendry). Goodwin and Schroeder, for example, use such a model to study spatial linkages in United States cattle markets. In the present study, however, cointegration models are used within a single market to study the joint movement of two commodity prices. In particular, if a market is efficient, prices of two commodities will not be co-integrated (Granger and Escribano). This provides a test which is somewhat counterintuitive. The logic is based on the fact that if two prices are co-

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[9] The cited study uses an assumption of additive separability in demand. While this was useful for the illustration to which it was applied, it is generally recognized as unrealistic.

integrated, there will be Granger causality in at least one direction (Granger). Such causality implies that one price series can be used to forecast movement in the other. This is a violation of one property of an efficient market. Since an inter-commodity spatial model includes both the spatial flow of goods and information, this principle is best addressed within a single market.

To illustrate the technique of testing co-integration, denote a discrete time series of a variable x_t which is stationary as I(0). Alternatively, if x_t must be differenced n times to be stationary, denote the series as I(n). We focus, in particular, on series that are I(1). This includes series that are random walks. Consider two such series. In general, a linear combination of these series will also be I(1). If there is a stable relationship between the two series, however, there will be a linear combination of the two series that is I(0). Such series are considered co-integrated.

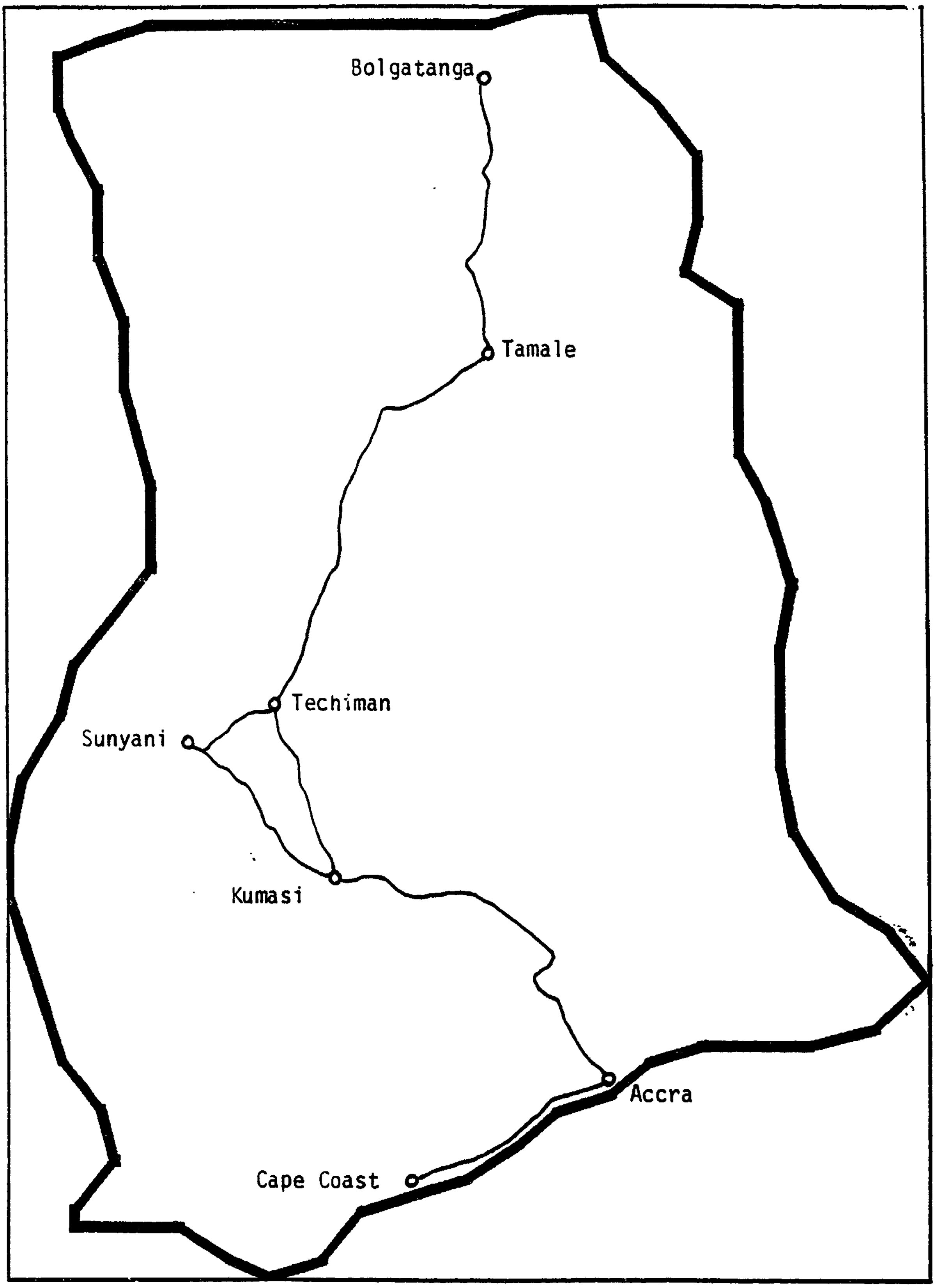
The test of co-integration, then, first requires testing whether the different price series are I(1) using, in our case, a test introduced by Dickey and Fuller (see also Engle and Granger; Schwert; Goodwin and Schroeder). This involves regressing $(x_t - x_{t-1})$ on x_{t-1} and testing the significance of the regression coefficient. Alternatively, one can regress $(u_t - u_{t-1})$ on u_t where u_t is the residual of a regression of the price around a mean and/or time trend. In either form of the test, the test statistic is based on a t-ratio. Critical values of this test statistic, however, differ from commonly used t-statistics, but distributions based on Monte-Carlo studies are available in the literature cited. The null hypothesis is that the series are I(1); the alternative that is generally accepted (to the degree that one can ever accept an alternative hypothesis) is that the data is I(0). The underlying intuition in this test is that large absolute values of the (generally negative) coefficients of lagged residuals indicates that changes in x_t or u_t will be reversed over time, that is, that they are stable.

If both series are I(1), one can proceed by regressing one price on the other. One then tests whether the residuals are I(1) using a Dickey-Fuller test as described above.

III. DATA AND RESULTS

To reiterate the procedures used in this study. We first test the degree of market integration in the standard one commodity model. This model is then expanded to a two commodity framework. The results of this model shed some light on the relationship of commodity prices - in particular, the expected speed of price transmittal across commodities. In order to investigate the efficiency that commodity price information is utilized, however, a second approach - that of cointegration - is also employed. This is not used to model spatial integration but rather looks at the relationship of commodity prices within a single market. Each of these approaches have features that are useful for our study of Ghana. The key is to adapt the models to the specific context under investigation.

The particular focus is the Upper East Region of Ghana, which is relatively poor and considered an area of food insecurity as indicated both by production variability and by higher levels of clinical malnutrition. It has the distinction of being the main millet producing and consuming region in the country, with sorghum being a secondary grain. Maize is only occasionally grown. The capital of the region (Bolgatanga) is linked to the maize exporting regions of the country (Brong-Ahafo and Ashanti) by a single trunk road (Map 1). The road is often impassable during and immediately after the rains. Long distance traders seldom stop along the route either to purchase or sell grain. Because of the linear nature of the trade link, then, and because the Upper East imports



Map of Ghana indicating transport routes linking the major markets.

maize, we can investigate the potential relation of other grain prices in the Upper East to maize prices using a recursive structure.[10]

We can take eq. (5) as explaining the formation of maize prices in the principal maize market, Techiman. This price will be influenced by a number of markets (denoted, say, by 2 through n-1). It is not, however, determined by the price in the Upper East, which, under an analogy with standard models in international trade, can be assumed to be a "small country" price taker. It is not essential, therefore, to consider P_1 (the maize price in Techiman) as simultaneously determined in estimations of P_n (the maize price in the main market in the Upper East, Bolgatanga).[11]

Identification is made easier by this assumption since it also implies that under competitive conditions the local price for commodity imported from the reference market (maize) is the c.i.f. price; changes in local demand should not influence this price although they will influence the quantity traded. This assumption implies that one need not consider even local maize prices as jointly determined with millet or sorghum prices. Simultaneity, however, can also run the other way; local millet prices can be affected by local demand, hence, by local maize prices. As such millet prices must be considered jointly determined with maize prices.

One needs to consider how the model structure would be affected if imports are temporarily suspended. This would not reverse the causality assumed in the

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[10] This is an important policy issue inasmuch as the government may intervene in the maize market, but is unlikely to do so for millet or sorghum.

[11] Following Ravallion, however, we do employ an instrumental variables technique, however, as P_1 may still be susceptible to errors in variables.

recursive model; Techiman prices would not be endogenous although Bolgatanga maize prices would be simultaneously determined with millet and sorghum.

The underlying assumption on this market structure can be tested in the analysis. The test for market segmentation offered by Ravallion (1986) will indicate not only the degree to which local price movements are integrated with those in the exporting region, but whether there are seasonal patterns in the link. Similarly, the model can also directly test the assumption that local demand conditions do not influence the market clearing price. In the present study these conditions are indicated by the prices of millet and sorghum as well as indirectly through seasonal dummy variables.

The data in this study are monthly wholesale prices from regional offices of the Ministry of Agriculture in Bolgatanga (Upper East) and Sunyani (Brong-Ahafo). Techiman, on the main north-south road in Brong-Ahafo, is taken as the reference market for maize. The data cover the period from 1977 to 1990.[12] Given the high level of inflation in the period covered, all prices are deflated using a CPI deflator. Some gaps exist in the data around 1983 as drought and a severe fiscal crisis contributed to a breakdown in administration capacity in that year. Wherever there is such a gap, of course, the lag structure requires that a number of periods for which information is available should also be excluded. Apart from a loss of information, however, this should not directly affect the estimation technique. Moreover, to test the sensitivity of results, alternative specifications were run in which all observations from the drought period covering 18 months in 1983 and 1984 were excluded. No change in any of the tests was observed in such explorations. The conclusions of the study also

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[12] Greater detail is available in Alderman and Shively (1991).

prove not to be sensitive to whether prices were specified in logarithms or levels. We, therefore, retain Ravallion's formulation in levels.

RESULTS OF THE DYNAMIC INTERREGIONAL MODEL

As mentioned, we also follow Ravallion in instrumenting prices in the reference market in the estimation of eq. 4. That is, the right hand side variables for Techiman prices in the subsequent analysis are predicted rather than observed prices in the reference market. This was done using Sunyani current and lagged prices with a correction for first-order serial correlation.[13] While more markets might improve the efficiency of the instrumenting equations, all other relevant market series contain gaps that would require a reduction in the sample size. The fit in the instrumenting equation was good, with an r^2 over 0.90. Again, none of the results reported below were particularly sensitive to the use or exclusion of instrumental variable techniques.

The next consideration is the appropriate length of the lag structure in the estimates of eq. 4. Test 1 in Table one indicates that adding one period lagged prices to a base model which regresses only the current price in Bolgatanga on the current Techiman price results in a significant improvement of

[13] This was deemed warranted by conventional analysis of the Durbin-Watson statistic. As this test is not appropriate when lagged values of the dependent variables are included on the right-hand side, Durbin's h statistic was used for initial diagnostics of a model of Bolgatanga maize price with a one-period lag (Durbin 1970). No evidence of serial correlation was revealed with this test, which used instrumented Techiman prices corrected for auto correlation as the independent price.

the model.[14] Moreover, a test of the restrictions on a four-period lag (test 3) leads to a rejection of the restriction that such a model is equivalent to one with prices lagged only one period, as in Timmer (1987) and Heytens. There was, however, no significant improvement in the model when prices were lagged more than four periods (test 4).

In none of the models was a seasonal dummy variable defined as 1 if the month was July, August or September - months during which roads are more likely to be impassable due to rain - significantly different from zero. Similarly, coefficients for a dummy variable defined as one if the observation came from the eighteen month drought period 1983-4 were not significant in any model.

Complete market segmentation implies that none of the Techiman prices significantly influence Bolgatanga prices. This can be rejected for maize, millet, and sorghum in Bolgatanga. On the other hand, short-run integration (as defined by Ravallion)--indicated by the coefficient of current Techiman prices being one--is also rejected in all models.[15] Test of the restrictions necessary for long-run integration--that all coefficients of current and lagged prices sum to 1--are reported in Table 1 (tests 5, 8, and ?). These restrictions are not rejected at plausible levels of significance.

This raises two questions: how long is "long run" and how powerful is the test of this restriction? Although there is reason to be concerned that any

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[14] In the interest of space, the table includes only tests of restrictions. For an indication of the parameters of selected models, see the equations under Figures 1 and 2. Additional details are available from the author.

[15] This is a necessary but not a sufficient condition. The hypothesis also implies certain restrictions on other parameters (see Ravallion 1986 and Faminow and Benson).

Table 1 - Test Statistics for Dynamic Model of Grain Markets in Bolgatanga

Model	Test	F-Statistic
Maize Base: Maize prices as a function of Techiman maize prices and period dummy variables.	Significance of model: $P^{BOMZ} = f(P^{TEMZ})$	$F(4,110) = 71.23$
1: Inclusion of 1-period lagged maize prices	$\alpha_{t-1}^{BOMZ} = 0,\ \beta_{t-1}^{TEMZ} = 0$ (Joint significance relative to base model)	$F(2,108) = 49.97$
2: Inclusion of 2-period lagged maize prices	$\alpha_{t-2}^{BOMZ} = 0,\ \beta_{t-2}^{TEMZ} = 0$ (Joint significance relative to Model 1)	$F(2,106) = 1.74$
3: Inclusion of 4-period lagged maize prices	$\alpha_{t-2}^{BOMZ} = 0,\ \alpha_{t-3}^{BOMZ} = 0,\ \alpha_{t-4}^{BOMZ} = 0,$ $\beta_{t-2}^{TEMZ} = 0,\ \beta_{t-3}^{TEMZ} = 0,\ \beta_{t-4}^{TEMZ} = 0$ (Joint significance relative to Model 1)	$F(6,102) = 3.39$
4: Inclusion of 5-period lagged maize prices	$\alpha_{t-5}^{BOMZ} = 0,$ $\beta_{t-5}^{TEMZ} = 0$ (Joint significance relative to Model 3)	$F(2,100) = 0.32$
5: Inclusion of 4-period lagged maize prices (same as Model 3)	Rejection of hypothesis that $\beta_{t}^{TEMZ} + \beta_{t-1}^{TEMZ} + \beta_{t-2}^{TEMZ} + \beta_{t-3}^{TEMZ} + \beta_{t-4}^{TEMZ} + \alpha_{t-1}^{BOMZ} + \alpha_{t-2}^{BOMZ} + \alpha_{t-3}^{BOMZ} + \alpha_{t-4}^{BOMZ} = 1$	$F(1,102) = 0.38$
6: Inclusion of 4-period lagged maize prices and 4-period lagged local millet prices	$\alpha_{t-1}^{BOMI} = 0,\ \alpha_{t-2}^{BOMI} = 0,\ \alpha_{t-3}^{BOMI} = 0,\ \alpha_{t-4}^{BOMI} = 0$ (Joint significance relative to Model 3)	$F(4,98) = 1.23$
7: Inclusion of 4-period lagged maize prices and 4-period lagged local sorghum prices	$\alpha_{t-1}^{BOGC} = 0,\ \alpha_{t-2}^{BOGC} = 0,\ \alpha_{t-3}^{BOGC} = 0,\ \alpha_{t-4}^{BOGC} = 0$ (Joint significance relative to Model 3)	$F(4,94) = 1.79$
Millet Base: Millet prices as a function of Techiman maize prices, lagged local millet prices and period dummy variables. Corresponds to model 3 with millet price as dependent variable.	Significance of model	$F(12,103) = 32.08$
8: (Same as Millet Base)	Rejection of hypothesis that $\beta_{t}^{TEMZ} + \beta_{t-1}^{TEMZ} + \beta_{t-2}^{TEMZ} + \beta_{t-3}^{TEMZ} + \beta_{t-4}^{TEMZ} + \alpha_{t-1}^{BOMI} + \alpha_{t-2}^{BOMI} + \alpha_{t-3}^{BOMI} + \alpha_{t-4}^{BOMI} = 1$	$F(1,103) = 0.15$
Sorghum Base: Sorghum prices as a function of Techiman maize prices, lagged local sorghum prices and period dummy variables. Corresponds to model 3 with sorghum price as dependent variable.	Significance of model	$F(12,98) = 41.56$
9: (Same as Sorghum Base)	Rejection of hypothesis that $\beta_{t}^{TEMZ} + \beta_{t-1}^{TEMZ} + \beta_{t-2}^{TEMZ} + \beta_{t-3}^{TEMZ} + \beta_{t-4}^{TEMZ} + \alpha_{t-1}^{BOGC} + \alpha_{t-2}^{BOGC} + \alpha_{t-3}^{BOGC} + \alpha_{t-4}^{BOGC} = 1$	$F(1,98) = 0.002$

Note: Superscripts denote the market and real commodity price as follows: BOMZ = Bolgatanga wholesale maize; TEMZ = Techiman wholesale maize; BOMI = Bolgatanga wholesale millet; BOGC = Bolgatanga wholesale sorghum.

model is unlikely to reject restrictions if it is imprecisely estimated, the overall significance of the model (and the fact that the r^2 of the various models range between 0.78 and 0.90) and the fact that it is robust to alternative respecification should allay that concern. The former question also has no strict test, but all of the estimated models with lagged prices are consistent with long-run integration. Tests similar to test 5 cannot reject the restriction of the sum of the price parameters for all models with one through five lagged values for prices. For example, the sum of the price parameters for the maize price model is 1.05 in a single lag model and 0.97 for a five- period lag.

As discussed above, under reasonable assumptions, maize prices in the Upper East, or in any other small importing regions, would be independent of the price of locally produced substitutes. Tests 6 and 7 test the joint significance of millet or sorghum prices in a variant of eq. 4 with 4 lagged values of maize prices. The four coefficients for lagged millet prices (or for sorghum) were individually and jointly not significa .. While this observation is important and is discussed further below, it is not a strict test of the hypothesis that the Bolgatanga maize price are determined by the price in Brong-Ahafo alone (the small country assumption) and, hence, of fully and instantaneously integrated markets. What is also needed is a test of whether contemporaneous millet or sorghum prices influence maize prices. Adding current millet and sorghum prices to models 6 and 7, respectively, indicated that contemporaneous millet and sorghum do influence local maize prices even after prices in Techiman are included; current millet and sorghum prices were statistically significant when added to the two models with t-values of 12.01 and 7.69, respectively. Recall, however, that short-run adjustment of Bolgatanga maize prices to those in

Techiman is also rejected in the model which reports maize prices alone. The simple price taker model discussed above implicitly assumes the type of contemporaneous price adjustment that is rejected.[16]

Looking at millet prices as a dependent variable indicates that movements in maize prices in the reference market (Techiman) largely explain movements in millet prices. More surprisingly, movement in local maize prices add no additional explanation to the model--that is, when Bolgatanga millet prices are regressed on current and lagged maize prices in Techiman as well as lagged Bolgatanga millet prices, the lagged Bolgatanga maize prices do not improve the fit of the model. This implies that local maize prices do not contain information that is not conveyed by Techiman maize prices and lagged millet prices. Similarly, when Techiman and lagged Bolgatanga maize prices are included in the model, millet prices add no additional information.

The situation, however, is somewhat different in the case of sorghum prices. While the two commodity version of Ravallion's dynamic price model also indicates that movements in Techiman maize prices influence the Bolgatanga sorghum price, lagged local sorghum and lagged local maize prices both contain information that is additional to that contained in the other set of prices when the current price of sorghum is the dependent variable. This is indicated by the joint significance of the respective block of prices when added to a model which includes current and lagged maize prices in Techiman as well as the alternative set of lagged prices from Bolgatanga.

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16 Clearly, one can accommodate the time lag for information and commodity flows in a more realistic model, but this is not necessary for our primary objectives.

Figures 1 and 2 indicate the speed and magnitude that price movements in the Techiman maize market transmit to millet and sorghum prices in Bolgatanga. These simulations show that a sustained increase of 10 cedis in the price of maize (1985 prices) leads to roughly a similar increase in the prices for the two other grains in the outlying market.[17] As indicated in the test of the sums of parameters above, the change is stable in the long run. A more transitory movement in the price of maize--say, a fluctuation that lasts only one period--will, of course, have a much smaller impact on the other market. Such effects, however, can easily be calculated with the type of model employed here.

The index of price transmittal that is estimated with this data using the modification of Ravallion proposed by Timmer (1987) and by Heytens is 0.42 (standard error = 0.106) for millet and 0.37 (standard error = 0.100) for sorghum. These are significantly different than 1, although the price transmittal in Figures 1 and 2 is close to or greater than one within three periods. Apparently, the short-lag structure that makes the index of market connectedness a transparent indicator in the Heytens-Timmer model also masks the degree of price transmittal. The IMC, nevertheless, retains a value as a summary measure by which to compare markets. The index is 1.76 for millet and 1.62 for sorghum using this data. This implies a greater contribution of local market information to current millet and sorghum prices than from Techiman maize prices. In contrast, similar models linking Techiman with five maize markets in Ghana (including Bolgatanga) resulted in IMC values between 0.23 and 1.01.

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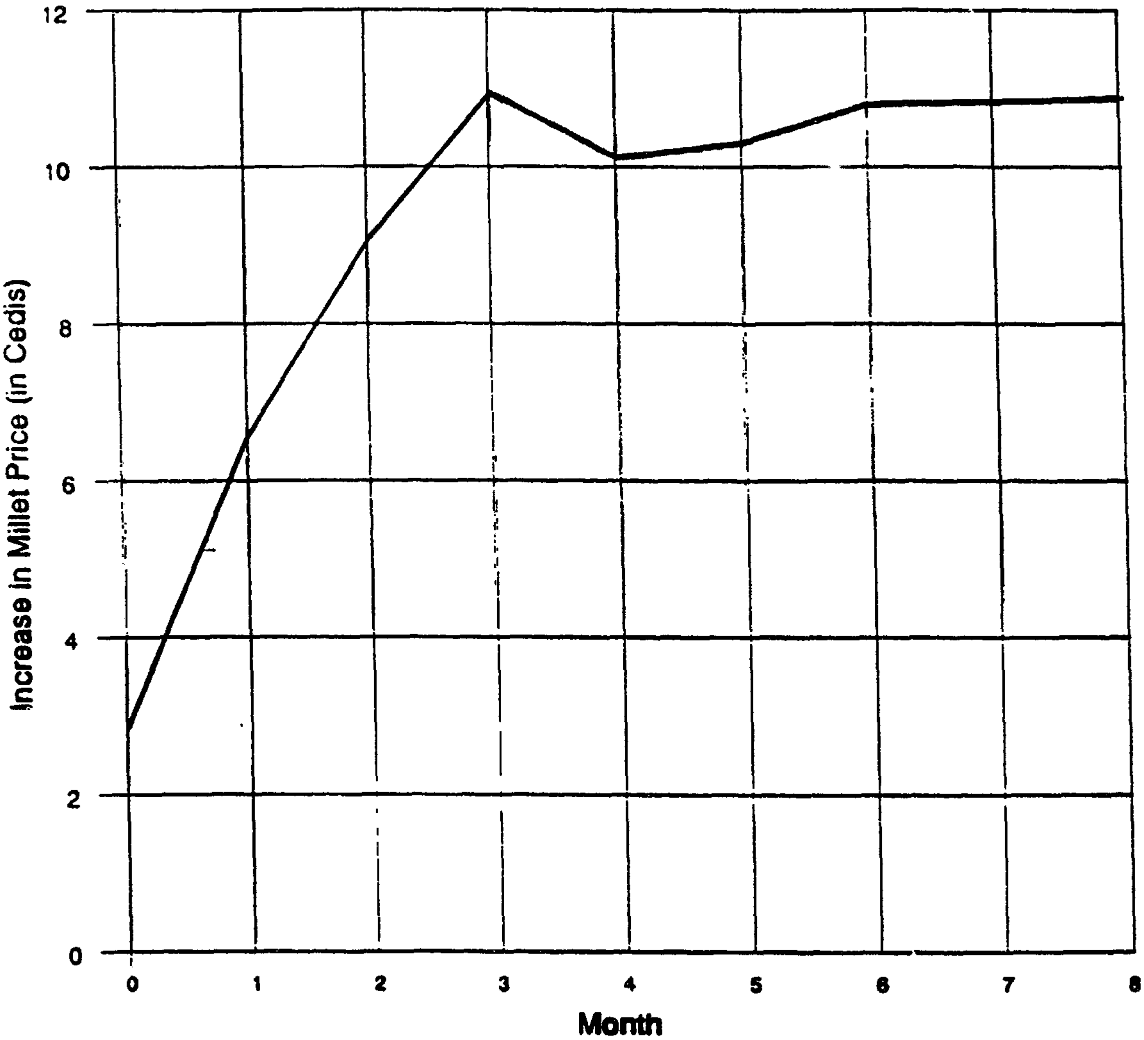
[17] Mean prices for maize, millet, and sorghum in Bolgatanga in the period covered were 29.6, 36.3, and 35.1, respectively.

Figure 1

Impact on Millet Price of a 10-Cedi Increase in Maize Price



Calculations are based on the following equation, which corresponds to model 8, Table 1:

$$P_{mi} = \underset{(0.50)}{2.01} + \underset{(2.50)}{0.284}\, P_{mz_0} + \underset{(1.59)}{0.230}\, P_{mz_{t-1}} + \underset{(1.36)}{0.052}\, P_{mz_{t-2}} - \underset{(0.06)}{0.009}\, P_{mz_{t-3}}$$

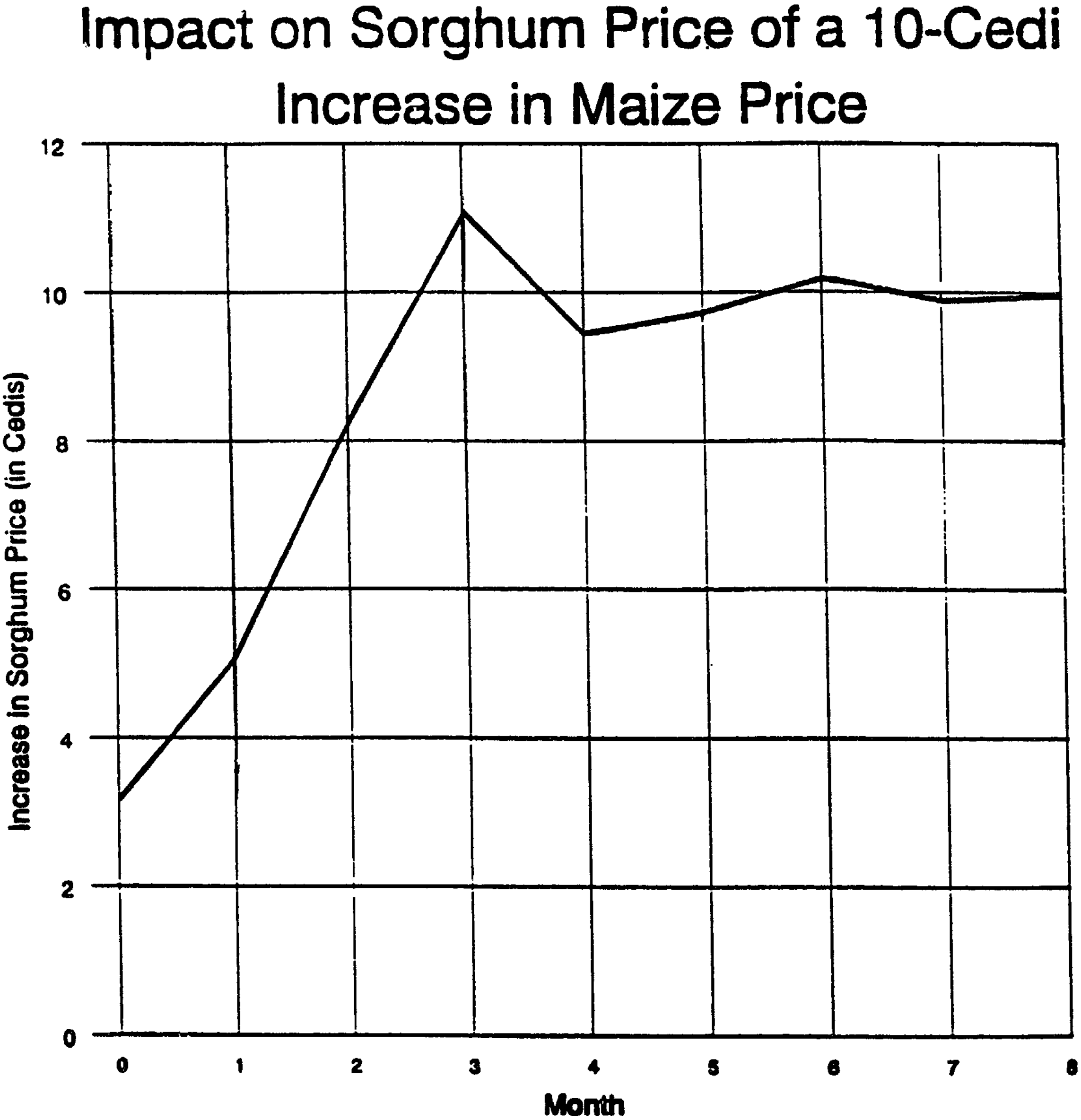
$$- \underset{(2.26)}{0.264}\, P_{mz_{t-4}} + \underset{(5.25)}{0.509}\, P_{mi_{t-1}} + \underset{(0.26)}{0.028}\, P_{mi_{t-2}} + \underset{(1.86)}{0.200}\, P_{mi_{t-3}}$$

$$+ \underset{(0.18)}{0.016}\, P_{mi_{t-4}} + \underset{(0.58)}{1.16}\text{ Rainy Season} - \underset{(0.15)}{0.401}\text{ Drought} - \underset{(0.819)}{1.596}\text{ Post 1984}$$

$$R^2 = 0.79$$

where P_{mi} indicates Bolgatanga millet prices, and P_{mz} are Techiman maize prices.

Figure 2



Calculations are based on the following equation, which corresponds to model 8, Table 1 (t-values in parenthesis):

$$P_{gc} = \underset{(1.04)}{3.55} + \underset{(3.07)}{0.316}\, P_{mz_0} + \underset{(0.42)}{0.055}\, P_{mz_{t-1}} + \underset{(1.52)}{0.198}\, P_{mz_{t-2}} - \underset{(0.38)}{0.050}\, P_{mz_{t-3}}$$

$$- \underset{(3.30)}{0.354}\, P_{mz_{t-4}} + \underset{(4.46)}{0.427}\, P_{gc_{t-1}} + \underset{(1.20)}{0.123}\, P_{gc_{t-2}} + \underset{(2.43)}{0.236}\, P_{gc_{t-3}}$$

$$- \underset{(0.55)}{0.048}\, P_{gc_{t-4}} + \underset{(0.97)}{1.77}\, \text{Rainy Season} - \underset{(0.10)}{0.25}\, \text{Drought} - \underset{(1.50)}{2.54}\, \text{Post 1984}$$

$R^2 = 0.84$

where P_{gc} indicates Bólgatanga sorghum (guinea corn) prices, and P_{mz} are Techiman maize prices.

The fact that the IMC is higher for coarse grains than for maize is consistent with the structure of the market discussed above and, to a degree, validates the model. Moreover, it is also noteworthy that only one of seven gari markets and two of nine yam markets in Nigeria studied by Heytens had an IMC lower than inter-commodity grain markets studied here. Furthermore, the inter-commodity values for the IMC are also lower than 5 of the nine Indonesian maize market values in Timmer's (1987) study even though Asian markets are widely presumed to function more efficiently than those in Africa. That is, the price linkage in the markets studied is comparatively strong relative to other developing countries.

RESULTS OF TESTS OF INTEGRATION AND COINTEGRATION

An alternative way of looking at the issue of information flows is to investigate co-integration within a single market. Table 2 reports tests of the integration of various price series as well of co-integration. The critical value reported in Engle and Granger is 3.37 at 5 percent level of significance and 4.07 at 1 percent. Schwert offers slightly different levels--levels which, moreover, vary if a trend variable is included. For our purposes, it is sufficient to note that one rejects the hypothesis that the series are I(1) unless one has a rather high critical value. The subsequent test of co-integration, then, must have at least the same critical values. The test of co-integration rejects the null hypothesis that the combination of the price series is I(1) at any plausible level of significance. The alternative hypothesis is

Table 2 - Tests of Integration, Co-Integration, and Granger Causality

Type of Test	Bolgatanga Market	Techiman Market
Test of Integration[a]		
Maize	$P_{mz_t} - P_{mz_{t-1}} = \underset{(-3.629)}{-0.152}\, P_{mz_{t-1}}$	$P_{mz_t} - P_{mz_{t-1}} = \underset{(-3.695)}{-0.128}\, P_{mz_{t-1}}$
Millet	$P_{mi_t} - P_{mi_{t-1}} = \underset{(-3.992)}{-0.170}\, P_{mi_{t-1}}$	$P_{mi_t} - P_{mi_{t-1}} = \underset{(-3.883)}{-0.226}\, P_{mi_{t-1}}$
Sorghum	$P_{gc_t} - P_{gc_{t-1}} = \underset{(-4.353)}{-0.219}\, P_{gc_{t-1}}$	$P_{gc_t} - P_{gc_{t-1}} = \underset{(-2.961)}{-0.153}\, P_{gc_{t-1}}$
Test of Co-Integration[b]		
Millet with maize	$\epsilon_{mimz_t} - \epsilon_{mimz_{t-1}} = \underset{(-5.084)}{-0.239}\, \epsilon_{mimz_{t-1}}$	$\epsilon_{mimz_t} - \epsilon_{mimz_{t-1}} = \underset{(-4.645)}{-0.293}\, \epsilon_{mimz_{t-1}}$
Sorghum with maize	$\epsilon_{gcmz_t} - \epsilon_{gcmz_{t-1}} = \underset{(-7.400)}{-0.485}\, \epsilon_{gcmz_{t-1}}$	$\epsilon_{gcmz_t} - \epsilon_{gcmz_{t-1}} = \underset{(-3.750)}{-0.216}\, \epsilon_{gcmz_{t-1}}$
Granger Tests of Causality	$\mu_{mi_t} = \underset{(0.14)}{-0.0811} + \underset{(1.17)}{0.1209}\, \mu_{mz_{t-1}} + \underset{(8.73)}{0.7106}\, \mu_{mi_{t-1}} - \underset{(0.26)}{0.487}\, drought$	$\mu_{mi_t} = \underset{(0.181)}{-0.193} + \underset{(4.30)}{0.529}\, \mu_{mz_{t-1}} + \underset{(6.82)}{0.477}\, \mu_{mi_{t-1}} - \underset{(0.49)}{0.437}\, drought$
	$\mu_{mz_t} = \underset{(0.17)}{-0.0838} + \underset{(9.31)}{0.814}\, \mu_{mz_{t-1}} - \underset{(0.58)}{0.040}\, \mu_{mi_{t-1}} - \underset{(0.59)}{0.942}\, drought$	$\mu_{mz_t} = \underset{(0.084)}{-0.048} + \underset{(12.17)}{0.713}\, \mu_{mz_{t-1}} - \underset{(2.27)}{0.084}\, \mu_{mi_{t-1}} - \underset{(0.41)}{0.522}\, drought$
	$\mu_{gc_t} = \underset{(0.21)}{0.1116} + \underset{(3.09)}{0.343}\, \mu_{mz_{t-1}} + \underset{(5.55)}{0.500}\, \mu_{gc_{t-1}} - \underset{(0.38)}{0.789}\, drought$	$\mu_{gc_t} = \underset{(0.26)}{-0.282} + \underset{(3.56)}{0.426}\, \mu_{mz_{t-1}} + \underset{(8.18)}{0.561}\, \mu_{gc_{t-1}} - \underset{(0.25)}{0.744}\, drought$
	$\mu_{mz_t} = \underset{(0.19)}{0.0979} + \underset{(9.06)}{0.775}\, \mu_{mz_{t-1}} - \underset{(0.16)}{0.0001}\, \mu_{gc_{t-1}} - \underset{(0.60)}{0.938}\, drought$	$\mu_{mz_t} = \underset{(0.05)}{-0.028} + \underset{(11.80)}{0.760}\, \mu_{mz_{t-1}} - \underset{(1.06)}{0.039}\, \mu_{gc_{t-1}} - \underset{(0.42)}{0.663}\, drought$

Note: Critical values are 3.37 for 5 percent level of significance and 4.07 for 1 percent.

[a] Dickey-Fuller statistic in parenthesis. Regressions use deseasonalized data.

[b] Dickey-Fuller statistic, where ϵ_{mimz} is the residual of millet prices regressed on maize prices, and ϵ_{gcmz} is the corresponding term with sorghum.

that the prices are co-integrated, hence, some imperfections in the use of information in this particular market.

Given the low power of the test for co-integration when both price series are virtually stationary themselves, it is useful, however, to augment these results with tests of Granger causality. With such a test, a significant coefficient on the lagged residual from a regression deseasonalizing the price of maize in a regression with current millet residuals as the dependent variable and lagged residuals for millet prices as an additional right hand side variable is indicative of causality.[18] This test did not reveal any evidence of maize prices in Bolgatanga influencing millet prices or vice versa (Table 2).

On the other hand, the test of co-integration of sorghum and maize prices in Bolgatanga was supportive of that hypothesis--that is, the hypothesis that a linear combination of the two prices series are I(1) is rejected. Again, however, the test needs to be augmented due to the, at best, borderline results for the initial tests of an I(1) price series for maize and the unambiguous rejection for sorghum prices; Granger causality tests indicate causality from maize to sorghum, but not vice versa.

Tests of Granger causality of prices in the Techiman market, however, indicate that maize prices influence sorghum prices <u>and</u> vice versa. Similarly there is a causal relationship from maize prices to millet prices in the Techiman market, although in this case the reverse relationship is less robust; the lagged residual of detrended millet is not significant if the sample excludes an 18

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[18] The initial regressions have the price as the dependent variable and dummy variables for months on the right-hand side. No trend variables are included, but prices are real prices. These regression as well as tests of cointegration and Granger causality with more than one lag period are available from the author.

month period of drought in 1983-84 (not illustrated in Table 2). No other tests of Granger causality are changed by restricting the sample to non-drought years. Similarly, here as with sorghum in Bolgatanga, including additional lagged residuals does not lead to a failure to reject the hypothesis of non-causality.

IV. CONCLUSION

The study looks at inter-commodity price transmittal from two perspectives. The first is a policy perspective: can the government concentrate on a single commodity price yet achieve price policy objectives in a broader arena? This is important in Ghana because no single commodity dominates consumers' food budgets, while for administrative and logistical reasons, direct interventions in all commodity markets are infeasible. Although the price transmittals indicated in Figures 1 and 2 are not in themselves justification of any interventions, they do imply that such policies are likely to have far reaching impacts.

While long-run price transmittal in the maize market is compatible with competitive assumptions, a one to one transmittal to other commodities is only one of many empirical possibilities consistent with competitive assumptions and cross-price response. Indeed, the level of price transmittal is surprising. It is possible, but not proven in this study, that traders set prices for other coarse grains in response to maize price information in a manner that requires supply changes (particularly storage buildup and drawdown) to bring markets into equilibrium. Note that it takes 3 months for the price shock to be fully transmitted. While in the long run this indicates market integration it remains puzzling why this transmittal exceeds the time necessary to move commodities between markets.

As indicated above, the adaptation of Ravallion's model to include commodities which are substitutes, also can be used to explore how much information is added when additional price series are included in the model. An alternative approach, which can be applied to a single market, is a model of co-integration. Despite the example of Granger and Escribano cited above, such models are more commonly applied to macroeconomic indicators. The explorations here faced a difficulty not uncommon in the literature; the technique is only conditional on the two-price series not being stationary. The tests of Granger causality, which are related to the co-integration model, reveal that the limited power of the latter model does not invalidate the premise that the broader issue of the information contained in alternative price series can provide insights on the working of commodity markets in developing countries.

This, then, is the second perspective from which the study looks at price transmittal. One notes some imperfections in the manner by which markets process information; the lagged price of maize in both markets conveys information that is not also contained in the past price of sorghum. This was also the case with millet in Techiman, but not in Bolgatanga. At the same time, sorghum prices convey information not signaled by maize prices in Techiman. If the drought period is included, millet prices also help predict maize prices in this market, although this result does not hold using the complete sample.

There are a number of possible explanations for this market inefficiency. For example, traders may not deal in all grains and, therefore, have different costs of acquiring information. This may be particularly the case with sorghum, which is used both for human consumption and used for making beer. Brewers, most of whom operate on a small scale, likely trade and store only sorghum. This commodity may then constitute a conceptually separate (although physically contiguous) market. It should be noted, however, that perfect price transmittal is often rejected even for speculative markets in developed countries in which information is generally available electronically and trade rarely requires the physically exchange of goods. From a practical viewpoint, the dynamic model of price integration indicates functional, if not perfect, efficiency of Ghanaian coarse grain markets.

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