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Market Reforms, Spatial Price Dynamics, and China's Rice Market Integration: A Causal Analysis with Directed Acyclic Graphs

Titus O. Awokuse

Previous studies on post-reform market performance of Chinese grain markets have produced mixed results. This paper employs province-level price data to determine if China's food market liberalization policies in the 1990s resulted in interregional rice market integration. Furthermore, this study extends the literature on spatial market integration by augmenting multivariate cointegration modeling techniques with directed acyclic graphs (DAGs), a recently developed statistical method for analyzing contemporaneous causal relationships. While the empirical results confirm the existence of strong market linkages subsequent to the reforms of the early 1990s, the linkages became less as the Chinese government reversed several reform policies in the mid-1990s. Overall, the empirical evidence from this study indicates that China's agricultural market policy reforms have been relatively effective.

Key words: directed acyclic graphs, grain prices, interregional trade, market liberalization, spatial price dynamics

Introduction

In recent years, many developing and transition economies have engaged in structural adjustment and market reform programs to liberalize their agricultural markets. These efforts were perceived as prerequisites for achieving efficient resource allocation and long-term growth in the agricultural sector. China, in particular, has experienced a rapid and significant level of growth in agricultural productivity (Diao, Fan, and Zhang, 2003). Many analysts attribute a significant portion of China's economic success to its economic liberalization policies and the reform of the food market distribution system (Lin, 1992; Sicular, 1995; Park et al., 2002). However, periods of market liberalization were also accompanied by cases of retrenchments (Park et al., 2002; De Brauw, Huang, and Rozelle, 2004).

In a recent study, Keller and Shiue (2004) tried to place China's economic growth into historical perspective by examining the linkages between economic reform, market integration, and domestic regional trade in China over the course of three centuries. However, despite the well-documented positive effects of the first phase of rural reforms on China's economy, disagreements persist on the relative impact of the second phase of rural market reforms on the integration of China's agricultural markets. This paper

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Titus O. Awokuse is assistant professor, Department of Food and Resource Economics, University of Delaware, Newark. The author thanks David Bessler, David Lambert, Scott Rozelle, Jian Yang, and an anonymous reviewer for their helpful comments and insights on improving earlier versions of this paper.

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reexamines the evidence on China's post-reform market performance by using recently developed causal modeling techniques to analyze the extent of market integration in domestic rice markets.

Recently, the analysis of spatial market integration has been used in assessing the effectiveness of liberalization policies in developing countries (Alexander and Wyeth, 1994; Goodwin, Grennes, and McCurdy, 1999; Park et al., 2002; Laping, 2004). Since tests of market integration usually investigate the extent to which price shocks are transmitted among spatially separated markets, such an analysis can provide information on price discovery and the extent of competitive behavior. Because of its position as both a large developing and transition economy, China provides an excellent case study on the impact of market liberalization policies on a transitional economy. In addition, grain markets are ideal for the study of spatial market integration because of the ability to compare prices across regions for such a relatively homogeneous commodity.

A majority of the past studies of the impact of market reforms on China's agriculture have focused primarily on allocative efficiency and productivity issues (Fan and Pardey, 1997; Lambert and Parker, 1998; Lin and Wen, 1995; Xu, 1999). Fewer studies have investigated the effects of the reform policies on distributive (or market) efficiency. Furthermore, the few studies available on post-reform market performance of Chinese grain markets have produced mixed and conflicting results. For instance, Wu (1994) used average rice prices to investigate the extent of market integration in China and found little or no evidence in support of market integration. However, inference from Wu's (1994) results may be limited by data deficiency as the study only had access to small rice price observations. Similarly, Zhou, Wan, and Chen (2000) used cointegration techniques to examine pairwise integration among China's major rice markets and found a general absence of integration among the markets. As an extension to the bivariate analysis performed by Zhou, Wan, and Chen, a multivariate analysis separating contemporaneous and dynamic causal relationships, as proposed here, could provide additional insights into the complex relationships among spatially separated markets.

In contrast to some previous analyses reporting a general lack of integration in China's grain markets, several empirical studies of Chinese grain market performance have found evidence in support of market integration (Rozelle et al., 1997; Park et al., 2002; Huang, Rozelle, and Chang, 2004). For example, Park et al. (2002) examined the impact of transition policies on China's grain market performance by using a parity-bounds model of interregional trade to analyze provincial grain prices from 1988 to 1995. They found that China's grain markets are integrated even in the presence of trade restrictions and other forms of government intervention. In addition, Huang, Rozelle, and Chang (2004) used cointegration techniques to examine more recent provincial grain price data (rice, soybean, and maize) covering 1996–2000. Although they found a few cases where markets pairs were not integrated, they also concluded that there has been significant progress made in China's grain market integration.

Overall, the results from past studies on the impact of market reforms in China have been mixed—finding evidence both in support of and against grain market integration in the 1990s. The relative conflict in the results from previous studies may be due to the paucity of data used in some of the analyses or the diversity in the empirical methods applied. Although previous studies have done well in applying modern time-series modeling methods (e.g., cointegration) to analyze *dynamic* (lagged) causal relationships, the nature of *contemporaneous* causal relationships in agricultural markets has been mostly ignored. Accordingly, this study seeks to bridge the gap in the literature by examining both contemporaneous and dynamic causal patterns among rice markets in southern China.

Specifically, the objective of this paper is to determine whether China's market liberalization policies in the 1990s had led to improved market performance in the grain sector or if the times of policy retrenchments had managed to stifle integration of the rice market. Rice price data are analyzed for six major provinces for the reform period (1991–2000) and the literature on spatial market integration is extended by augmenting the popular multivariate cointegration modeling methods with directed acyclic graphs (Swanson and Granger, 1997; Pearl, 2000; Bessler, Yang, and Wongcharupan, 2003). In contrast to previous studies, the combination of directed acyclic graphs techniques and error correction modeling allows for complementary analysis of both contemporaneous and dynamic causal relationships among spatially separated markets. To the author's knowledge, this study is the first to apply the directed acyclic graphs (DAG) modeling approach to the analysis of Chinese agricultural markets.

Empirical results from the present study suggest that despite periods of reform retrenchments, the market liberalization policies of the 1990s successfully led to significant integration of Chinese rice markets. This result further confirms prior findings which also showed empirical support for integration of Chinese grain markets in the 1990s (Rozelle et al., 1997; Park et al., 2002; Huang, Rozelle, and Chang, 2004). The remainder of the paper is organized as follows. First, a brief overview is provided of China's economic reforms, with emphasis on the key policy changes and retrenchments. The conceptual modeling framework is then presented, followed by a description of the statistical methodology. Next, a section is devoted to the empirical results of the study. Concluding remarks are given in the final section.

Overview of China's Agricultural Reforms

Beginning in the 1950s, the government played a major role in planning and controlling China's agricultural production and distribution. Pre-reform government stabilization policies included grain price controls in urban areas, rationing of state grain sales, and a state-monopolized procurement and marketing system. Although the collective farming system and China's grain self-sufficiency policy provided a favorable growth environment for the industrial sector, they created production disincentives to farmers and resulted in considerable misallocation of resources in the agricultural sector (Lin, 1992).

While the agricultural reform program can be traced back to the late 1970s when the initial emphasis was on the decollectivization of agricultural production, the liberalization of the state-controlled agricultural distribution system did not occur until later. De Brauw, Huang, and Rozelle (2004) noted that China's market reform policies can be divided into two distinct stages: the incentive reforms period (1979–1984) and the gradual market liberalization period (1985–1995). The first phase ("incentive reforms") is captured by the Household Responsibility System (HRS) reforms which began in the early 1980s. During the first phase of rural agricultural reforms which focused on the decentralization of the production system, free grain markets were encouraged as the "people's commune system" was abolished and farmers in the grain sector were allowed to gradually privatize their operations. The primary goal of decollectivization was to reassign the property rights of farmers and correct for the disincentives against high productivity inherent to collective farming systems (Lin, 1992). Thus, individual rural farmers were afforded more freedom in making decisions about crop choices and local production (Lin, 1992; De Brauw, Huang, and Rozelle, 2004).

The second phase of the reform process emphasized the liberalization of rural markets through the establishment of marketing institutions and competitive pricing mechanisms. In 1985, after three decades, the Chinese state-controlled grain procurement system (i.e., the "unified grain sale system") was discontinued and replaced with the "contractual grain procurement system." By late 1993, grain purchases in most urban markets were at market prices, since the state urban grain subsidies had practically been eliminated (Zhou, Wan, and Chen, 2000). In the early 1990s, the pace of rural grain market liberalization was accelerated. Specifically, the government introduced policies that encouraged commercialization of rural grain through the removal of the gap between government and market prices and the reduction of mandatory delivery quotas (Sicular, 1995). In subsequent years, important market institutions were organized (e.g., wholesale markets, futures markets, and information systems) (Park et al., 2002).

In late 1993, China's grain prices rose dramatically and the ensuing food price inflation led to the restoration of pre-reform policies such as rationing. Consequently, in the mid-1990s, the Chinese government attempted to combat inflation through increased food imports and had to reverse some of its previous reform policies. Similar to an earlier episode of policy retrenchment during 1988–1989, the second wave of policy retrenchments during 1994–1995 was characterized by increased government intervention in the grain market. In order to stabilize grain prices, the government retreated once again from its past market reforms by restricting rural grain trade and restoring grain rationing to consumers. Also, new government price control policies were instituted in order to artificially maintain affordable prices for scarce staple food and prevent political unrest in the populous urban areas (Zhou, Wan, and Chen, 2000).

During the latter years of the 1990s, China experienced a high level of surplus grain production and falling prices. This motivated the government to return to policies of stronger state controls. In contrast to earlier retrenchment policies in the mid-1990s, the government used different policy measures. For example, government policy shifted from one of taxation of grain farmers to price support and some protections from imports which guaranteed price floors higher than market equilibrium prices. This is analogous to an income support program for grain producers. Further, the government restricted private grain trade between farmers and non-government entities.

By 2001, the government had reverted to market liberalization policies. Although some may argue that the reform policy reversals have limited effects, the two episodes of retrenchments of market reform policies in the 1990s had the potential to scale back previous gains from earlier liberalization of China's agricultural markets. The extent of the impacts of the retrenchment policies on market integration is an empirical question requiring further investigation. Hence, in this paper, structural stability tests are used to examine potential structural break points.

Conceptual Modeling Framework

Samuelson (1952) and Takayama and Judge (1964) outlined the theoretical model of spatial competitive equilibrium which is a basis for the analysis of spatial market integration. If there is physical flow of goods (trade) between two markets, then commodity arbitrage activities by profit-seeking economic agents are expected to force market prices to a unique equilibrium where price differentials are equal to interregional transportation costs (which include other transactions costs of arbitrage).

Formally, the spatial arbitrage relationship could be represented by:

$$(1) \quad \begin{aligned} |P_{xt} - P_{yt}| &\le z \quad \text{if } Z_t = 0, \\ P_{xt} + z &= P_{yt} \quad \text{if } Z_t > 0, \\ P_{xt} - z &= P_{yt} \quad \text{if } Z_t < 0, \end{aligned}$$

where $Z > 0$, P_{xt} and P_{yt} are autarky prices for two spatially separated markets, and z denotes transportation costs between locations x and y. It is assumed that x is a net exporter to y. Two spatially separated markets are described as segmented if the price differential between the two markets is less than transportation costs, in which case trade does not occur. In contrast, two markets are said to be integrated if the actions of traders cause the price differential between the spatially separated markets to converge toward transportation costs (Bowen, Hollander, and Viaene, 1998, p. 337; Fackler and Goodwin, 2001, p. 977). When the markets are in equilibrium, the price difference should be less than or equal to transportation costs.

Assuming no policy-driven trade barriers or other forms of impediments exist, arbitrage will occur when the differential of autarky prices is greater than transportation costs. Thus, transportation costs (and other transactions costs) are particularly important in the definition and testing for spatial market integration. Unfortunately, most empirical analyses of market integration and efficiency are constrained by the lack of adequate data on transportation costs. Hence, most empirical studies assume that transportation cost is fixed and subsequently investigate the existence of market integration (efficiency) by focusing on linkages between observed market prices.

Given the interrelationships between trade barriers, transportation costs, and interregional trade, it is possible to use the theoretical model of spatial competitive equilibrium to provide a conceptual framework for testing alternative hypotheses about the potential effects of changes in China's agricultural policy reforms and retrenchments on the extent of rice market integration in the 1990s. Feenstra (2004, p. 154) provides further explanation of the linkages between distance, transportation costs, and interregional trade. It is reasonable to hypothesize that China's agricultural market reform policies which eliminate trade barriers and reduce transactions costs should lead to more efficient and more integrated grain markets. Also, it is hypothesized that the degree of market linkages should decline in response to the reversals of market liberalization policies as observed in China in the mid-1990s. Finally, it is hypothesized that relative to other markets, contiguous Chinese provinces engaged in arbitrage should exhibit a higher degree of market integration because of the trade-promoting effect of lower transportation costs. Empirical evidence of market integration from DAG and time-series analysis would indicate support for these hypotheses.

Empirical Methodology

The concept of spatial competitive equilibrium is captured by the "law of one price" (LOP). Although the integration of spatially dispersed markets is an indication of the tradability of commodities between markets, it does not necessarily imply that markets are perfectly competitive. Empirical tests of market integration usually investigate the extent to which price shocks in local markets are transmitted among spatially separated markets. Early analyses of market integration and the LOP often examined variations of models of price relationships where fluctuations in one market are transmitted to the second market. Empirical tests for the LOP are commonly based on a variation of equation (1) given by:

$$P_{xt} = \alpha + \beta_1 P_{yt} + \beta_2 Z_t + e_t, \tag{2}$$

where e_t denotes the residuals. The strict version of the LOP is assumed to hold if $\beta_1 = 1$, and $\alpha = \beta_2 = 0$. Similarly, the weak version of the LOP is satisfied if $\beta_1 = 1$, and $\alpha \neq 0$, $\beta_2 \neq 0$. The weak version of the LOP is more commonly observed in the real world. Variations of equation (2) are often estimated using bivariate static regression in first differences or in logarithms (Fackler and Goodwin, 2001). However, this approach has been criticized as inappropriate in capturing the dynamic long-run relationships among commodity prices when the price series are nonstationary. In such a case, the cointegration modeling technique is the more appropriate estimation method as it could be used to test for the weak version of the LOP.

The majority of recent investigations of spatial market integration have used time-series modeling techniques such as vector autoregression (VAR) techniques, Granger-causality tests, and cointegration analyses. The popularity of the VAR-type models is partly due to the well-documented potential for spurious correlation and other inferential limitations of earlier studies based on simple correlation and static regression analysis. Fackler and Goodwin (2001) argued that the use of forecast error variance decompositions (FEVDs) and impulse response functions (IRFs) from VAR models allows for more accurate inferences about market integration. But in order to identify the structure of the VAR innovations, it is first necessary to impose a particular causal ordering of the variables using Choleski or Bernanke factorizations of the reduced-form error covariance matrix. These identification schemes can be subjective and arbitrary, as theory does not always yield a clear identifying causal structure for spatially separated food markets. In recent studies, some researchers (see Swanson and Granger, 1997; Awokuse and Bessler, 2003; Bessler, Yang, and Wongcharupan, 2003) have advocated the use of directed acyclic graphs (DAGs) as an alternative data-determined approach to assigning contemporaneous causal relationships and identifying restrictions for structural VAR models.

Contemporaneous Causality Analysis with Directed Acyclic Graphs (DAGs)[1]

Directed acyclic graph theory is an increasingly popular subfield of discrete mathematics with numerous applications to various practical problems in the natural and social sciences. Graph theory can be divided into two branches: areas of undirected graphs and directed graphs (or digraphs). Although undirected graphs have been studied more extensively in the natural sciences, directed graphs have more relevant

[1] This section follows closely from Awokuse and Bessler (2003) and Bessler, Yang, and Wongcharupan (2003). Only a brief overview of DAG and its application is provided here, since more detailed explanations are given elsewhere (see Pearl, 2000; Spirtes, Glymour, and Scheines, 2000).

applications to economics and other social sciences, especially in the analysis of causal relationships. The majority of past investigations of causal relationships among economic variables use the Granger (1969) causality framework which builds on the knowledge that a cause precedes its associated effect (and thus an effect does not precede its cause). But recently, Spirtes, Glymour, and Scheines (2000), and Pearl (2000) proposed DAG as a more general framework for describing causal relationships.

In contrast to Granger's (1969) definition of causality, directed acyclic graphs allow for non-time sequence asymmetry in causal relations. The concept of conditional independence forms the foundation for understanding directed acyclic graphs. A DAG can be defined as a picture using arrows and vertices to represent the causal flow among a set of random variables. The vertices (variables) of these graphs can represent random variables on which data have been obtained, and line segments connecting vertices (directed edges or arrows) are generated by calculations of conditional statistical dependence or independence among pairs of variables (ceteris paribus). Alternatively, a DAG is a graph that contains only directed acyclic paths (i.e., no variable is allowed to be a direct or indirect cause of itself). Two vertices (variables) are connected only if a direct association exists between them. However, two variables cannot be connected if they are conditionally independent, given other variables in the system.

For example, if there is a directed edge $Q \rightarrow P$, the variable Q is described as the parent of P, while P is described as the child (or descendant) of Q. In this case, Q is a direct cause of P. In addition, a graph represented by $P \leftarrow X \rightarrow Q$ implies that the three variables P, Q, and X have a relation such that X causes P and Q. This causal relationship implies that the unconditional association between P and Q is nonzero but the conditional association between P and Q, given the knowledge of the common cause X, is zero. The common cause X can potentially screen off associations between their joint effects. Alternatively, if we have a scenario where both X and Q cause P, represented as $X \rightarrow P \leftarrow Q$, then the unconditional association between X and Q is zero. However, the conditional association between X and Q, given the common effect P is not zero.

Following Pearl (2000) and Spirtes, Glymour, and Scheines (2000), directed acyclic graphs can be used as an analytical tool to represent conditional independence as implied by the recursive product decomposition:

$$\text{(3)} \qquad \Pr(x_1, x_2, x_3, \ldots, x_n) = \prod_{i=1}^{n} \Pr(x_i \mid pa_i),$$

where Pr is the probability of vertices $x_1, x_2, x_3, \ldots, x_n$, and pa_i represents the realization of some subset of the variables that precede x_i in order $(x_1, x_2, x_3, \ldots, x_n)$. Pearl (2000) showed that the conditional independence relations given by equation (3) could be represented by d-separation (directional separation). Pearl's concept of d-separation can be illustrated as follows. For any three disjoint subsets X, Y, W vertices in a DAG, W is said to d-separate X from Y if there is no active causal link from X to Y given W. The concept of d-separation is a graphical characterization of conditional independence summarized in DAG. Pearl's work on d-separation is significant because it shows the link between the causal graphs and the underlying probability distribution of the data-generating process.

As in Awokuse and Bessler (2003), Fisher's z-statistic can be used to test estimated sample correlations and conditional correlations against zero. Fisher's z is expressed as:

(4) $$z\left(\rho(i,j \mid k), n\right) = \left[\tfrac{1}{2}\sqrt{n - |k| - 3}\,\right] \ln\left\{ \frac{|1 + \rho(i,j \mid k)|}{1 - \rho(i,j \mid k)} \right\},$$

where n is the number of observations used to estimate the correlations, $\rho(i,j \mid k)$ is the population correlation between series i and j conditional on series k, and $|k|$ is the number of variables in k. If i, j, and k are normally distributed and $r(i,j \mid k)$ is the sample conditional correlation of i and j given k, then the distribution of $z(\rho(i,j \mid k)n) - z(r(i,j \mid k)n)$ is standard normal. Similar to Swanson and Granger (1997), the causal path suggested by this data-driven approach is then used in a vector autoregression (VAR) model to construct forecast error variance decompositions (FEVDs).

Spirtes, Glymour, and Scheines (2000) developed a causal search algorithm (PC algorithm) for building directed acyclic graphs. The PC algorithm uses a stepwise testing of conditional independence for removing statistically insignificant edges (causal links) between variables and directing causal flow of information between the variables. Edges among a set of N variables (e.g., residuals from a VAR) are removed sequentially based on the observed zero correlation and partial correlation (conditional correlation). As shown in figure 1(a), the algorithm starts with a complete undirected graph, where innovations from every variable are connected with innovations from every other variable in the system. Then, the algorithm removes edges sequentially between variables. Next, the direction of causal flow is assigned between variables which remain connected after all possible conditional correlations have been determined to be nonzero. The PC algorithm and its more refined extensions are available as the software package TETRAD II (Scheines et al., 1994). Also, more detailed discussions of DAG and its applications can be found in the writings of Pearl (2000); Spirtes, Glymour, and Scheines (2000); Bessler, Yang, and Wongcharupan (2003); and Awokuse (2006).

Dynamic Causality Analysis with Cointegrated VAR Models

While contemporaneous relationships can be described with DAG, the analysis of the dynamic spatial market relationships between price series is best modeled with cointegration or error correction models (ECMs). This is appropriate because this estimation technique explicitly accounts for the presence of unit roots common to most time series. Ignoring unit roots in cointegrated price series could result in spurious correlations and biased parameter estimates. Multivariate cointegration tests are usually estimated as a reduced form of a VAR model. Since the cointegration and ECM methodology is fairly commonplace and well documented elsewhere (Engle and Granger, 1987; Johansen, 1988, 1992), only a brief summary is provided here.

Johansen (1988, 1992) modeled time series as reduced-rank regression and computed the maximum likelihood (ML) estimates in the multivariate cointegration model with Gaussian errors. Johansen's multivariate cointegration model is based on the error correction representation given by:

(5) $$\Delta \mathbf{P}_t = \boldsymbol{\mu} + \sum_{i=1}^{k-1} \boldsymbol{\Gamma}_i \Delta \mathbf{P}_{t-i} + \boldsymbol{\Pi} \mathbf{P}_{t-1} + \boldsymbol{\varepsilon}_t,$$

where $\mathbf{P}_t$ is an $(n \times 1)$ column vector of n variables (rice prices), $\boldsymbol{\mu}$ is an $(n \times 1)$ vector of constant terms, $\boldsymbol{\Gamma}$ and $\boldsymbol{\Pi}$ represent coefficient matrices, Δ is a difference operator, k

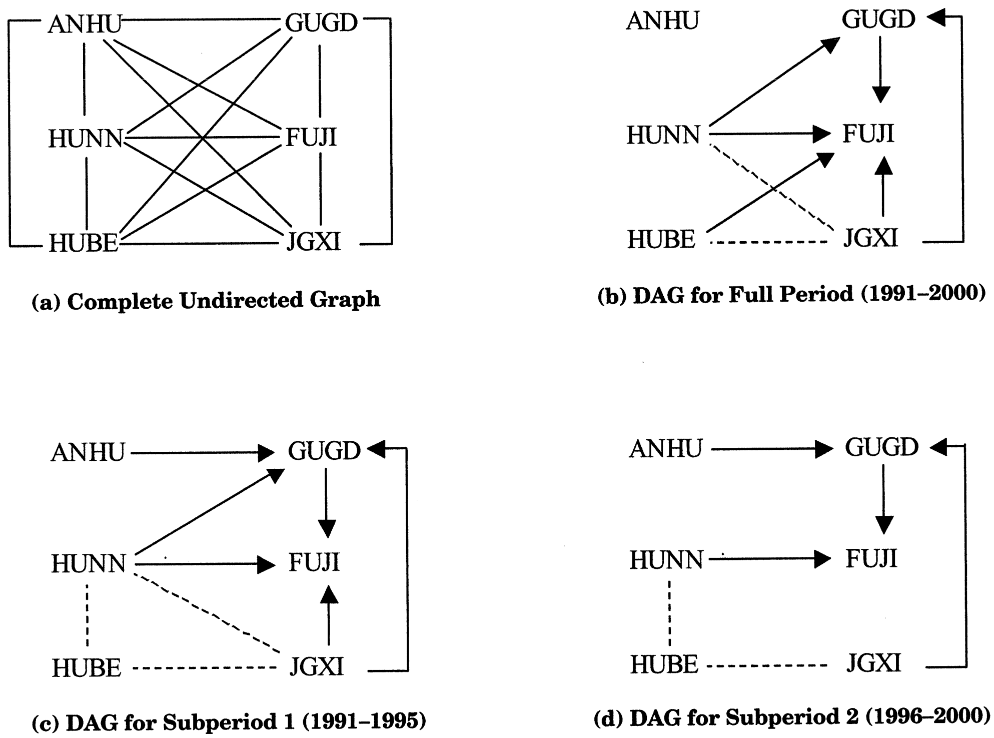

Figure 1. Directed acyclic graphs on innovations from an error correction model for rice prices in six Chinese provinces

denotes the lag length, and $\boldsymbol{\varepsilon}_t \sim N(0, \Sigma)$. The coefficient matrix $\boldsymbol{\Pi}$, known as the impact matrix, contains information about the long-run relationships. If the rank of $\boldsymbol{\Pi}$ is a positive number r and is less than n, then there exist matrices $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ with dimensions $n \times r$ such that $\boldsymbol{\Pi} = \boldsymbol{\alpha}\boldsymbol{\beta}'$. The matrix $\boldsymbol{\alpha}$ measures the strength of the cointegrating vectors and captures the short-run adjustments to long-run relationships. In contrast, the matrix $\boldsymbol{\beta}$ denotes the number of cointegrating vectors in the ECM. In the latter case, the linear combination represented by $\boldsymbol{\beta}'\mathbf{P}_t$ is stationary, even though $\mathbf{P}_t$ is not. Johansen's approach requires the estimation of equation (5) and using the residuals to compute likelihood-ratio test statistics which are then used to determine the cointegrating vectors of $\mathbf{P}_t$.

Since it is well known that the parameter estimates generated by VAR-type models (cointegration and ECM) are rather difficult to interpret, most researchers rely on innovation accounting for investigating the short-run dynamics of multiple time series. Innovation accounting involves the investigation of how a one-time shock is transmitted through the system via the analysis of forecast error variance decompositions (FEVDs) and impulse response functions (IRFs). Similar to Bessler, Yang, and Wongcharupan (2003), we adopted data-determined causal patterns suggested by DAG as an alternative to arbitrary choice of causal orderings of the contemporaneous innovations.

Results and Discussion

Data Properties

Six southern China provincial rice markets which trade predominantly in the indica rice market were selected for this analysis. These six markets can be divided into two groups: the net producing provinces and the net consuming provinces. The net producing provinces are Anhui (*ANHU*), Hubei (*HUBE*), Hunan (*HUNN*), and Jiangxi (*JGXI*), while the net consuming provinces are Fujian (*FUJI*), and Guangdong (*GUGD*). Data for several excluded markets (e.g., Shanghai) were either incomplete or unavailable. These six provinces capture the majority of the indica rice markets in China, accounting for almost 70% of rice production and 80% of China's internal rice trade (Luo, 1999; Zhou, Wan, and Chen, 2000). For example, the province of Guangdong is a central market with high rice demand for its increasingly metropolitan and industrial population. In Guangdong, much of the agricultural land has been diverted to housing and industrial development use.

The data were obtained from a data set gathered by China's National Market Administration Bureau (NMAB).[2] These prices represent the average of prices reported every 10 days in periodic local markets in each province. The data cover 10 years (1991–2000) and all data series are in natural logarithms. Given the potential for structural breaks from the government policy changes in the 1990s, three formal tests for structural stability were applied to the data. Results from the examination of recursive residuals, CUSUMSQ tests and Chow break-point tests suggest possible breaks in 1995:4 and 1998:9. Estimation using the latter break point was not feasible due to degrees-of-freedom constraints. Therefore, the estimation was conducted for the full sample and for two subperiods that accounted for the structural break in 1995 (i.e., 1991–1995 and 1996–2000). These subperiods are consistent with similar analyses reported by Rozelle et al. (1997) and Huang, Rozelle, and Chang (2004). Thus, current results could be compared to the findings from previous studies. While the first subperiod is considered by most China experts as a period of market liberalization, the second subperiod represents periods of policy retrenchment. This characterization of the 1990s in China's grain market reform environment is consistent with earlier investigations by other experts on China's economy (Sicular, 1995; Luo, 1999; Park et al., 2002).

Unit Root and Cointegration Tests

As proposed by Kwiatkowski et al. (1992), time-series univariate properties were examined using two unit root tests: the augmented Dickey-Fuller (ADF) (1979) test and the KPSS Lagrange multiplier (LM) test. While the ADF procedure tests for the null hypothesis of nonstationarity, the KPSS procedure tests for the null hypothesis of stationarity. The combination of the ADF and KPSS tests is a form of confirmatory analysis that has been shown to be more robust in determining the presence of unit roots (Kwiatkowski et al., 1992, p. 176). A combination of both test results for the full sample and for each of the two subperiods confirms that all the variables are I(1) since

[2] Special thanks are extended to Scott Rozelle and Min Chang who graciously provided the data set used in this study. Park et al. (2002) provide additional details on data sources and the collection process.

they are nonstationary in levels, but stationary in first differences. (Results for unit root tests are available from the author upon request.)

Since the data series are I(1), it is possible that there may be cointegration relationships between two or more provincial price series. If the markets operate under pure competition, for n markets, there should be $n - 1$ long-run relationships (cointegrating vectors) as the possibility of arbitrage between markets provides the economic mechanism for linkages. Assuming a fixed or negligible transportation cost, the LOP suggests that efficient trade and arbitrage activities should lead to price equalization for a spatially separated homogeneous commodity. However, it is possible to have spatially linked markets even in the absence of perfect competition. This is possible in cases where the market linkages are due to other factors such as government intervention policies (e.g., wage and price controls), similar climatic influences on agricultural harvest, and imperfect competition via price leadership by dominant firms or markets.

Results of Johansen trace tests (with and without linear trend in the cointegrating vector space) are presented in table 1. Following Johansen (1992), a sequential testing procedure was used. Starting from the topmost row of table 1, first test for zero cointegrating vectors ($r = 0$) assuming there is a constant in the cointegrating space (Tr^* statistic). If this hypothesis is rejected, then test for $r = 0$ assuming that the constant is *not* in the cointegrating space (Tr statistic). If this hypothesis is rejected, next test for $r \leq 1$ with a constant in the cointegrating space. This sequential testing process continues until the first time the result indicates failure to reject the null hypothesis. The trace test results for the full sample and each of the two subperiods suggest varying degrees of cointegration. For instance, for the full sample (1991–2000), four cointegrating relations exist, while only three and two cointegrating relations exist for the two subperiods (1991–1995 and 1996–2000), respectively. The cointegration test results suggest these six rice markets are spatially linked in the long run, but a little bit less integration was observed in the second subperiod. This finding implies that several markets are connected together through market arbitrage activities—which is plausible in light of the market liberalization policies that targeted the promotion of interregional grain trade.

Directed Acyclic Graph (DAG) Results

The results from multivariate cointegration tests only provide information on long-run relationships, but do not explicitly indicate which markets are linked and the causal direction of the price signals in both contemporaneous and dynamic (lagged) time. Thus, after establishing the existence of spatial price linkages with cointegration tests, applications of other statistical tools are necessary to establish the nature of the causal relationships among the rice markets. Directed acyclic graphs were constructed for sorting out the contemporaneous causal patterns among the six rice markets.

Figure 1 contains the directed acyclic graphs (DAGs) based on innovations from a six-variable ECM for the full sample and each subperiod. The graph was obtained via the application of the PC algorithm.[3] In figure 1(b), a general inspection of the DAG for

[3] Spirtes, Glymour, and Scheines (2000, p. 116) note that the significance level used in making decisions with the PC algorithm for constructing directed acyclic graphs should decrease as the sample size increases (and vice versa). They advocate the use of higher significance levels (e.g., 0.2) in order to improve performance and convergence at small sample sizes. Since data availability limits the current analysis to 1991–2000 and the data span is further limited in size by the subperiods of policy reforms and retrenchments, a significance level of 0.2 was used.

Table 1. Johansen Trace Test for Cointegration

Null r	Full Period (1991–2000)	Subperiod 1 (1991–1995)	Subperiod 2 (1996–2000)	C(5%)[a]
	----------- Tr* Statistics		-----------	
$r = 0$	167.753[b]	143.926[b]	116.670[b]	102.14
$r \leq 1$	98.305[b]	93.329[b]	76.267[b]	76.07
$r \leq 2$	64.653[b]	56.947[b]	50.643	53.12
$r \leq 3$	38.161[b]	29.382	27.572	34.91
$r \leq 4$	18.498	10.850	12.864	19.96
$r \leq 5$	2.168	2.469	2.935	9.24
	----------- Tr Statistics		-----------	C(5%)
$r = 0$	166.279[b]	135.346[b]	108.950[b]	94.15
$r \leq 1$	96.868[b]	84.883[b]	69.804[b]	68.52
$r \leq 2$	63.962[b]	52.494[b]	44.639	47.21
$r \leq 3$	37.498[b]	24.934	25.505	29.68
$r \leq 4$	18.123[b]	8.415	11.111	15.41
$r \leq 5$	1.827	0.071	1.309	3.76

Notes: In the first column, r denotes the number of cointegrating vectors for the cointegration test with constant within and outside the cointegrating vectors. "Tr*" denotes test with constant in the cointegrating vector; "Tr" denotes test without a constant in the cointegrating vector, but a constant outside the vectors.

[a] Denotes test statistics and critical values for results with constant within the cointegrating vectors.

[b] Denotes rejection of the null hypothesis of cointegration rank r at the 5% significance level.

the full sample period (1991–2000) reveals that the net importer markets (*GUGD* and *FUJI*) are receivers of price signals, while the net exporter markets are senders of price signals in contemporaneous time. For example, *HUNN* sends instantaneous price information to provincial rice markets in *GUGD* and *FUJI*. Similar causal flow of price information goes out from *HUBE* and *JGXI* markets who are major producers of rice. The undirected links represented by the dotted lines reflect the existence of a connection between the two markets but the links are not strong enough for the DAG algorithm to be able to assign the direction of contemporaneous causality.

Figure 1(c) contains the directed graphs for the first subperiod (1991–1995) characterized mainly by market liberalization policies. The causal linkages here are very similar to those observed for the full sample where there are six directed causal links among the markets. There are significant causal linkages from net producing regions to net consuming regions (e.g., from *HUNN* to *GUGD* and *FUJI*, and from *JGXI* to *FUJI* and *GUGD*). However, during this time period, we also observe a causal linkage from *ANHU* (another net exporter) to *GUGD* (the largest rice importer in southern China). In contrast, there are fewer price linkages among the rice markets in contemporaneous time during the second subperiod (1996–2000) which was characterized by cases of policy retrenchments [see figure 1(d)]. Instead of the six contemporaneous causal links found in the first subperiod, we now have only four. This outcome may be reflecting the effects of the reactionary retrenchment policies of the Chinese government that reestablished interregional grain trade barriers and eroded earlier market development gains from previous reform policies. The persistent causal link from *GUGD* to *FUJI* is particularly curious since both provinces are net importers of rice. This contemporaneous link may be highlighting the ease of transmission of market price information between these two geographically contiguous provinces.

Several of the contemporaneous causal linkages identified by DAG are consistent with the established trade routes in the regional grain transactions discussed by Luo (1999) and Zhou, Wan, and Chen (2000). For example, the increasing urbanization and development pressures in the Pearl River Delta area in Guangdong have transformed this area from a grain surplus area to the largest grain deficit region. Consequently, *GUGD* and *FUJI* are major importers of rice from neighboring rice producers in Hubei, Hunan, and Jiangxi. Furthermore, DAG results in figure 1 suggest that markets in contiguous provinces exhibit instantaneous transmission of price information. Close geographical proximity of rice markets could be assumed to be trade-enhancing as it may imply relatively lower transactions costs. Feenstra (2004, pp. 154–158) showed that growth in trade across spatially separated regions depends on changes in transportation costs and other forms of trade barriers. In empirical analysis of trade, distance is commonly used as a proxy for transportation costs because detailed transportation costs are not readily available. Thus, the result from this study is plausible, implying that lower inter-provincial trade restrictions via food market liberalization policies resulted in lower transactions costs of grain marketing and consequently an increase in observed market integration.

Forecast Error Variance Decomposition (FEVD) Results

Although there are connections between the grain markets in contemporaneous time, this finding may be weakened (or strengthened) as we study results from the lagged relationships (from the VAR models). Dynamic analysis via forecast error variance decompositions may provide additional insights into how market liberalization (and retrenchment) policies affect rice prices after a time lag.

The variance decompositions are obtained through the shocking of the VAR equation for each of the six variables by one standard deviation of the innovation term. Based on the DAG results in figure 1(b)–(d), FEVDs for the six rice markets are presented for the full sample and two subperiods in tables 2, 3, and 4, respectively. The FEVDs allow for the determination of which of the provincial rice market prices are statistically exogenous or endogenous relative to each other at various forecast horizons. Although the price shocks occur at 10-day intervals, the variance decomposition results are summarized for horizons of 1, 2, 3, and 9 months. In each table, the first column in the output for the FEVDs is the standard error of the forecast for each rice price series. The standard error, which captures the level of uncertainty, becomes larger as the forecast horizon increases. The remaining columns report the error variance decompositions. After adjusting for number rounding, each row should add up to 100%.

As shown in table 2 for the full sample period (1991–2000), the most significant result is the dominant influence of two of the four net producing provincial markets in the study: *HUBE* and *JGXI*. The only dominant net consuming market is *GUGD*. These markets show dominance as they accounted for greater than 11% of the price variations in most of the other markets. For example, *HUBE* is very influential in the longer horizons (9 months ahead), explaining a sizeable proportion of the variability in rice prices in each of the other five markets. These results suggest that significant grain market integration occurred in provincial rice markets subsequent to the institution of

Table 2. Forecast Error Variance Decompositions on Chinese Rice Prices, Full Period (1991–2000)

Horizon	Standard	Error Variance Decompositions					
(Month)	Error	*ANHU*	*FUJI*	*GUGD*	*HUBE*	*HUNN*	*JGXI*
ANHU							
1	0.06	100.00	0.00	0.00	0.00	0.00	0.00
2	0.08	94.06	0.28	1.01	4.09	0.45	0.12
3	0.09	87.60	0.80	2.79	7.84	0.36	0.61
9	0.14	42.14	1.93	***15.89***	***28.41***	0.16	***11.47***
FUJI							
1	0.05	0.00	92.04	4.55	1.16	0.95	1.31
2	0.07	0.12	80.82	***11.24***	2.75	1.56	3.50
3	0.08	0.20	68.86	***14.79***	8.24	2.23	5.68
9	0.13	0.61	26.29	***26.52***	***28.19***	1.36	***17.04***
GUGD							
1	0.04	0.00	0.00	97.60	0.00	2.05	0.34
2	0.06	0.21	0.46	88.29	7.53	1.28	2.23
3	0.08	0.14	0.34	82.19	***11.87***	0.86	4.60
9	0.14	0.87	0.21	55.12	***28.13***	0.31	***15.37***
HUBE							
1	0.04	0.00	0.00	0.00	100.00	0.00	0.00
2	0.08	0.12	2.57	1.76	88.87	0.06	6.62
3	0.10	0.45	4.58	3.10	79.98	0.10	***11.79***
9	0.17	1.83	3.52	***14.46***	57.94	0.08	***22.18***
HUNN							
1	0.05	0.00	0.00	0.00	0.00	100.00	0.00
2	0.07	0.01	1.74	4.05	0.21	93.56	0.43
3	0.08	0.03	2.55	9.76	0.41	85.61	1.63
9	0.13	0.24	1.56	***33.13***	***15.41***	37.66	***12.01***
JGXI							
1	0.05	0.00	0.00	0.00	0.00	0.00	100.00
2	0.08	0.09	0.93	0.86	3.38	0.73	94.02
3	0.09	0.20	1.47	4.03	8.08	1.37	84.86
9	0.14	1.21	0.76	***22.00***	***23.36***	0.94	51.74

various market-liberalizing policy reforms in the early 1990s. It is also notable that the majority of the markets in provinces with close geographical proximity exhibit significant price linkages. For example, rice prices in contiguous provinces [*HUBE-ANHU* (28.41%), *HUBE-GUGD* (28.13%), *JGXI-GUGD* (15.37%), *HUBE-JGXI* (23.36%), etc.] are spatially linked. The strong price linkages between *HUBE* (a major rice producer) and *JGXI* (a major rice producer and consumer) are not unexpected, since they are neighboring provinces that share transportation connections via roads, railroads, and waterways. Thus, it is reasonable to assume price information can be easily and quickly transmitted between these two important rice markets.

Similar to the findings for the full sample period reported in table 2, results for the two subperiods (tables 3 and 4) also indicate significant levels of integration between the regional rice markets. Once again, *HUBE* and *JGXI* appear to have a strong influence on other rice markets; shocks to rice prices in these two net producing markets result

Table 3. Forecast Error Variance Decompositions on Chinese Rice Prices, Subperiod 1 (1991–1995)

Horizon (Month)	Standard Error	Error Variance Decompositions					
		ANHU	*FUJI*	*GUGD*	*HUBE*	*HUNN*	*JGXI*
ANHU							
1	0.06	100.00	0.00	0.00	0.00	0.00	0.00
2	0.08	92.34	1.11	1.13	4.98	0.28	0.16
3	0.10	83.85	3.02	2.54	10.17	0.23	0.19
9	0.16	33.10	4.20	***30.20***	***24.79***	0.49	7.23
FUJI							
1	0.06	1.51	89.43	3.16	0.00	4.65	1.25
2	0.07	2.14	71.64	***14.36***	3.20	5.25	3.43
3	0.08	2.36	55.76	***25.70***	7.80	4.22	4.17
9	0.16	1.45	14.69	***48.62***	***22.08***	2.04	***11.14***
GUGD							
1	0.04	0.00	0.00	97.80	0.00	0.76	1.43
2	0.07	0.17	0.13	85.30	10.11	1.10	3.19
3	0.09	0.15	0.30	77.26	***14.82***	1.80	5.68
9	0.18	1.75	0.60	61.35	***22.36***	1.98	***11.96***
HUBE							
1	0.04	0.00	0.00	0.00	100.00	0.00	0.00
2	0.07	0.22	4.03	5.32	83.59	0.23	6.62
3	0.09	0.21	5.73	***11.49***	71.02	0.22	***11.33***
9	0.20	1.49	2.57	***43.26***	36.95	0.99	***14.74***
HUNN							
1	0.04	0.00	0.00	0.00	0.00	100.00	0.00
2	0.06	1.04	7.57	***11.00***	1.53	76.13	2.73
3	0.07	1.25	7.42	***25.75***	7.31	51.64	6.64
9	0.17	1.25	2.53	***50.03***	***22.70***	10.90	***12.59***
JGXI							
1	0.06	0.00	0.00	0.00	0.00	0.00	100.00
2	0.09	0.58	0.52	1.83	4.18	0.27	92.62
3	0.10	1.34	0.43	8.45	9.34	0.26	80.18
9	0.18	2.95	0.51	***38.85***	***19.69***	1.17	36.84

in significant fluctuations in rice prices in the other markets. Also notable in the first subperiod (1991–1995) is the causal link from *GUGD* to the other five markets. This reflects the dominant position the Guangdong market holds in the southern China rice trade. It is reasonable to expect that price shocks due to changes in demand in the heavily populated Guangdong province could be transmitted to other markets in the region. Interestingly, the influence of Guangdong on other markets became less significant in the second subperiod (1996–2000, table 4). The reversal of reform policies which reduced provincial grain trade flows is a possible reason for the reduction in market linkages between Guangdong and the other markets in the second subperiod. Grain suppliers to Guangdong had to significantly curtail inter-provincial export of rice. For example, Luo (1999, p. 51) notes that Jiangxi, a major supplier of rice to Guangdong, "cut [its] volume of grain sales by two-thirds in the first quarter of 1994, compared with the same period in 1993."

Table 4. Forecast Error Variance Decompositions on Chinese Rice Prices, Subperiod 2 (1996–2000)

Horizon (Month)	Standard Error	Error Variance Decompositions					
		ANHU	*FUJI*	*GUGD*	*HUBE*	*HUNN*	*JGXI*
ANHU							
1	0.05	100.00	0.00	0.00	0.00	0.00	0.00
2	0.07	93.96	1.62	0.35	3.24	0.48	0.35
3	0.08	89.85	1.46	1.02	5.09	0.64	1.95
9	0.13	46.64	0.94	1.53	***17.98***	4.25	***28.67***
FUJI							
1	0.05	0.00	86.11	6.74	7.09	0.00	0.06
2	0.06	1.50	80.37	10.46	5.53	0.43	1.71
3	0.06	3.34	73.22	9.15	5.75	0.46	8.09
9	0.10	6.02	31.11	3.93	***16.10***	2.70	***40.14***
GUGD							
1	0.04	0.00	0.00	99.06	0.00	0.00	0.94
2	0.05	0.62	1.72	88.26	7.74	0.22	1.46
3	0.06	1.84	1.23	78.23	***15.28***	0.27	3.15
9	0.11	4.76	0.63	28.93	***28.77***	4.31	***32.61***
HUBE							
1	0.05	0.00	0.00	0.00	100.00	0.00	0.00
2	0.08	0.07	0.71	0.33	88.55	0.98	9.35
3	0.09	0.23	1.06	0.25	77.98	2.84	***17.64***
9	0.14	1.01	1.23	0.13	48.77	7.20	***41.66***
HUNN							
1	0.04	0.00	0.00	0.00	0.00	100.00	0.00
2	0.06	0.93	0.20	0.55	0.11	98.12	0.10
3	0.07	3.48	0.18	0.78	0.16	95.14	0.26
9	0.09	14.19	0.15	2.30	5.72	64.48	***13.16***
JGXI							
1	0.03	0.00	0.00	0.00	0.00	0.00	100.00
2	0.06	0.33	3.60	0.17	1.50	0.56	93.84
3	0.07	1.24	5.68	0.12	4.02	0.46	88.47
9	0.11	4.50	5.43	1.10	***16.36***	1.67	70.94

Alternatively, the degree of market integration can be assessed by examining the speed of adjustment of regional prices to unexpected shocks—i.e., the more exogenous a regional rice price is, the less integrated is that market with the other market prices. For example, in both the first and second subperiods, *ANHU* is exogenous in the first month since 100% of variability in its local rice prices was explained by its own variability. In the first subperiod, the *ANHU* price became slightly less exogenous in subsequent horizons as the own-share of price variability significantly decreased to 92.34% and 86.85% in the second and third months, respectively. In contrast, the Fujian market is relatively more integrated with other regional prices; the own-share of its price variability was 89.43% in the first month, decreasing to 71.64% and 55.76% in subsequent months. These results are consistent with the reality of rice production and consumption in China since *ANHU* is mainly a producer of japonica rice while the other provinces produce and consume mainly indica rice. Thus, it is reasonable that *ANHU*'s rice prices are relatively less integrated with those of the other rice markets. Alternatively, the result for *ANHU* could also be interpreted as evidence pointing to the low level of substitutability between indica and japonica rice varieties. Similar conclusions could be drawn from the results in the second subperiod.

Overall, this study's finding of strong market integration during the reform period of the early 1990s supports the hypothesis that the reforms were effective in expanding private grain market transactions in China. This result is consistent with findings in earlier studies which concluded that China's grain market has improved since the market reform process began (Rozelle et al., 1997; Park et al., 2002; De Brauw, Huang, and Rozelle, 2004). In addition, the potentially negative impact of retrenchment policies in reversing previous gains in grain market integration appears to be marginal.

Concluding Remarks

There is an ongoing debate about the relative impact of China's agricultural market reforms on the integration of its domestic grain markets. Although the positive impacts of the first phase of rural "incentive reforms" on China's agricultural economy have been well documented, disagreements persist on the relative impact of the second phase of rural market reforms on the performance of China's agricultural markets. While several analysts argue that China's market liberalization policies have been effective in improving agricultural market performance (Lin, 1992; Sicular, 1995; Park et al., 2002), others have expressed doubts, contending China's agricultural markets became less integrated during the course of the reforms and the accompanying retrenchment periods (Luo, 1999; Young, 2000; Zhou, Wan, and Chen, 2000).

This paper utilized the recently developed modeling technique of directed acyclic graphs (DAG) in combination with error correction models to determine the extent of spatial price linkages among six major Chinese rice markets during the market reform era of the 1990s. Causal relationships between rice prices were investigated contemporaneously (using DAG) and dynamically (using forecast error variance decompositions). Current findings suggest that post-reform Chinese rice markets are integrated as price signals in one market are quickly transmitted to other markets. Causal analysis, contemporaneously (via DAG) and dynamically (via variance decompositions), suggests there are three dominant net producing rice markets (Hubei, Hunan, and Jiangxi) where price information originates and is then transmitted to the other provincial rice markets. In the long run, price shocks in these three rice markets explain significant levels of price fluctuations in the other markets. In addition, Guangdong, the largest net consuming rice market in China, also had a significant influence on price movements in rice markets in neighboring provinces. This analysis also provides what appears to be an intuitive result about the importance of relative geographical proximity of transportation linkages between markets. Rice markets that share the same provincial borders exhibit a significantly higher degree of price linkages in both the short and long run.

To some degree, the empirical evidence from this study indicates that Chinese agricultural policy reforms have been relatively effective. An important policy insight from this empirical study is that market liberalization policies which manage to remove internal trade barriers and lower transactions costs would enhance domestic market integration and efficiency. Current results also suggest that public investments designed to improve the proper functioning of private food marketing channels are useful tools for improving food access for consumers in low-income countries and thereby help address issues of food insecurity. Furthermore, the empirical methodology and results from this paper have important implications for food policy research in developing economies. Application of the directed acyclic graphs method as a tool for assigning contemporaneous causal flows in the context of VAR-type models can be particularly useful for researchers investigating market performance in developing and transition economies where there are several constraints to obtaining accurate market price data. Finally, a data-determined method for discovering causal relationships can be invaluable to researchers as it could complement limited prior knowledge from economic theory on how regional markets are interrelated.

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