Chapter 17

SPATIAL PRICE ANALYSIS

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Abstract

Agricultural commodities are typically produced over an extensive spatial area and are costly to transport relative to their total value. These characteristics yield a complex set of spatial price linkages which are often studied to gain insights into the performance of markets. An extensive literature has addressed a wide range of issues relating to spatial price linkages. Issues relate to market conduct and performance, regional and international trade relationships, efficiency, and developing economy market performance. This chapter reviews issues related to economic and empirical models of spatial price linkages. The relative weaknesses and merits of each approach are identified.

Keywords

spatial equilibrium, price analysis, law of one price, market integration, market efficiency

1. Introduction

Agricultural commodities are typically produced over an extensive spatial area and are costly to transport relative to their total value. Spatial patterns of marketing give rise to a complex web of relationships among prices throughout a market, and spatial price analysts study these relationships in order to gain insight into the workings of the market and evaluate its performance. For many markets, prices are the only data readily available to examine spatial relationships.

This chapter attempts to develop a common framework for spatial price analysis in order to shed light on what conclusions can be drawn about spatial market relationships. It attempts to carefully distinguish between economic models of price determination and the statistical techniques used to analyze price behavior. The bulk of empirical studies of spatial prices of homogeneous goods have been conducted using either correlation, static regressions, or dynamic regressions, such as vector autoregressions. Many studies of spatial prices express hypotheses about market efficiency and integration in terms of restrictions on the regression parameters. We develop a simple economic model to provide a better understanding of these restrictions and the conditions under which they are appropriate.

Tests that can be justified in the context of the simple model should be thought of as joint tests of market efficiency, market integration, and the equilibrium model. Presuming the model is correct, failure to pass these tests can be due either to a breakdown in the integration of the market or to some form of market inefficiency. An empirical model may, however, suffer from a variety of misspecification problems that may lead to erroneous inferences. For example, it is possible that an empirical model does not capture important features of the market being examined. Unfortunately, many of the methods that can be rigorously justified within the context of a simple model of spatial price formation cannot be supported when the assumptions of the model are relaxed.

In the remainder of this introduction we describe some of the main areas of application of spatial price analysis. We then discuss a number of concepts important in the study of spatial markets, including spatial arbitrage, the law of one price, market integration, and spatial market efficiency. The chapter then discusses the main theoretical models that underlie the study of spatial price behavior and that can be used to interpret the empirical work in this area. Alternative econometric approaches and empirical applications are then examined. The paper concludes with a summary and overall assessment of the literature.

1.1. Applications of spatial price modeling

1.1.1. Market definition and antitrust regulation

A considerable amount of early work in spatial price analysis in agriculture was devoted to defining markets. Many of these studies attempt to determine if spatial marketing patterns conformed with the then recently developed models of spatial equilibrium. For example, some studies analyzed either flow data or regional production and consumption data along with transport cost data in an attempt to determine if inefficiencies existed in marketing patterns. It was also common in the 1950s and 1960s to construct spatial price surfaces to define regional commodity markets. This work is well described in the text of Bressler and King (1970) and the review article by Weinschenck, Henrichsmeyer and Aldinger (1969), and will not be further covered here.

Antitrust regulation, especially the regulation of mergers, turns on the definition of a market. Although the idea of a market is among the most basic concepts of economics, its precise definition is problematic. At issue is the extent to which firms located in spatially separated regions actively compete. A merger between competing firms may result in a significant loss of competition. If the regions are not currently engaged in active competition, the merger, presumably, would have no such anti-competitive impact. The U.S. Department of Justice's merger guidelines specify a 5 percent rule, defining an antitrust market to be one consisting of regions that, if controlled by a single firm, would result in a price increase of at least 5 percent. The notion of an antitrust market is distinct from the more familiar notion of an economic market, which is generally taken to mean a spatial area "within which the price of a good tends toward uniformity, allowance being made for transportation costs" [Stigler(1966, p. 85)].

Methods similar to those used to evaluate integration have been used to define markets for regulatory purposes. These include the use of numerous statistical criteria including simple price correlations [Stigler and Sherwin (1985)], as well as methods based on dynamic regressions including Granger causality and cointegration. Switching regime models have also been used to examine the extent of a market [Spiller and Huang (1986), Spiller and Wood (1988)]. Such price-based methods have also been criticized, notably by Werden and Froeb (1993).

Recently, several studies have applied spatial price analysis to examine market power in agricultural industries. Faminow and Benson (1990) used econometric tests usually used to examine market integration to draw conclusions concerning noncompetitive behavior in the Canadian pork industry. Several studies commissioned by the U.S. Packers and Stockyards Administration used a variety of methods, including cointegration and impulse analysis and the Spiller and Wood switching regime model, to define regional market boundaries for fed cattle [Hayenga et al. (1996)].

1.1.2. Regional and international trade modeling

The notion of spatially integrated markets, typically expressed as the Law of One Price (LOP) or Purchasing Power Parity, is an essential ingredient in modern and classical models of international trade and exchange rate determination.[1] Theories regarding international price equalization and symmetrical international price changes are usually

[1] Purchasing power parity is a version of the law of one price for aggregate prices. If an entire collection of traded goods' prices adhere to the law of one price, an index of these prices will satisfy an equivalent condition, which is referred to as purchasing power parity.

thought to have originated in the work of Cassel (1918). There are, however, much earlier references to the notion of price equalization through trade in international markets. There are numerous references to the idea of price parity throughout the works of the bullionist period and in Ricardo (1817), Mill (1848), and later in Marshall (1890).

As Chambers and Just (1979) note, most analyses of exchange rates and international trade explicitly assume adherence to the law of one price in absolute terms. Officer (1982) surveys much of the early literature and finds that support for the law of one price is limited, especially in the short run. Williamson (1986) noted that the law of one price has probably been more thoroughly discredited by empirical evidence than any other proposition in the history of economics.

Although the empirical evidence against the LOP in its simple form is strong, supportive evidence does exist for modified versions of it. For example, the LOP is more strongly supported for traded than non-traded goods [Officer (1986)] and in its long-run than its short-run form [Protopapadakis and Stoll (1986)]. Empirical studies that explicitly account for transactions costs also tend to provide support for the LOP [Crouhy-Veyrac et al. (1982), Goodwin (1992a), Michael et al. (1994)]. Indeed, ignoring transactions costs can lead to serious econometric problems [Davutyan and Pippenger (1990)].

Spatial integration of factor markets also has an important role in modern theories of international trade. Neoclassical trade theories hold that, under certain restrictive conditions, equalization of output prices through trade and arbitrage will ensure that input prices are also equalized, even if inputs are not tradable. The notion of factor price equalization was introduced by Samuelson (1949). Mokhtari and Rassekh (1989) found that factors influencing the integration of goods markets (such as trade openness and similar factor endowments) had an important impact on the integration of factor markets. The issue of integrated international factor markets became a topic of considerable debate during deliberations over the North American Free Trade Agreement (NAFTA). The theory predicts that, as trade barriers are lowered and output markets become more integrated, factor prices will converge. The implication for U.S. workers was taken to be that NAFTA would lower wages among unskilled manufacturing workers. Lawrence and Slaughter (1993) investigated real wage gaps and found that the predictions of the theory were not supported by the empirical evidence. Leamer (1994) provided an alternative interpretation of these findings and pointed out that they were not necessarily inconsistent with the predictions of Samuelson's (1949) theory in that certain restrictive assumptions inherent in the theory were unlikely to be satisfied.

The issue of equalization of land prices has received considerable attention in the empirical literature. Alston (1986) obtained results supporting factor price equalization for international real land prices. Benirschka and Binkley (1994) found that price variability for homogeneous parcels of land increased as the distance to output markets increased. They concluded that increased variance was due to the effect of the transactions costs associated with moving output to market on output prices received by farmers. Goodwin and Ortalo-Magne (1992) evaluated factor price equalization for wheat-producing regions in the U.S., France, and Canada. Their results indicated that significant differences in land prices existed, but that policy changes under the General Agreement on

Tariffs and Trade (GATT) that brought about integration of international wheat markets would bring about a tendency for land prices to move closer together in these regions.

In general, the conditions necessary for adherence to factor price equalization and thus integration of factor markets are much stronger than those required for the integration of output markets. In particular, input market integration requires output markets to be integrated. In addition, factor price equalization also requires identical technologies among countries, constant returns to scale, fewer factors than goods, homogeneous factors of production, and the absence of specific factors of production [see Dixit and Norman (1980) for more on these restrictions]. In light of the strength of these requirements, it is not surprising that evidence supporting factor market integration is weak.

A number of studies have attempted to go beyond tests of spatial arbitrage conditions and estimate spatial price transmission ratios [Bredahl et al. (1979), Roe et al. (1986)]. In general, these studies have concluded that, in cases where domestic production and consumption are insulated from the world economy, changes in world commodity prices do not result in corresponding changes in domestic prices. Gardner and Brooks (1994) examined within-country (regional) price transmission ratios in the former Soviet Union, and found them to be affected by the distance between markets and by regional policies that may inhibit the flow of commodities among regional markets.

1.1.3. Market integration in developing economies

Considerable attention has been given to the analysis of spatial market integration in the context of developing economies that are often characterized by market fragmentation due to poor transport and communications infrastructure, inadequate contract enforcement mechanisms, and unstable political environments. Early work in this area concentrated on examining price correlations, but this practice was strongly criticized [Harriss (1979)] and replaced by more sophisticated statistical measures. Recent work has tended to use dynamic regression analysis and has generally concentrated on testing specific hypotheses rather than measuring the degree of market integration.

A number of questions have been raised in this literature that relate to the extent of integration among regions. For example, the degree to which specific regions can withstand economic shocks (especially weather-induced supply shocks) depends, in part, on the reliability of trade linkages with other regions [Ravallion (1986)]. The impact of market liberalization on producer and consumer welfare both depends on and affects the degree of integration through the opening of new markets and reduction in risk [Barrett (1996)]. The extent of market integration is also of importance in designing agricultural price stabilization policies. Stockpiling policies, for example, may need to be implemented in a decentralized fashion if production regions are poorly integrated.

2. Definitions

A number of distinctly different concepts are used to describe market linkages across space, time, and form. Indeed, the terminology is often loosely applied, such that the same words may involve distinctly different concepts in different studies. Before reviewing the literature, a consideration of the various terms and definitions applied in the literature is in order. Due to the lack of agreement on terminology, we shall attempt at the outset to define several terms that will be used throughout this discussion, as well as to note alternative usage of the terms.

2.1. Spatial arbitrage

Perhaps the least ambiguous concept in spatial price analysis is the notion that the actions of spatial arbitrageurs will ensure that the prices of a homogeneous good at any two locations will differ by, at most, the cost of moving the good from the region with the lower price to the region with the higher price

$$p_j - p_i \leqslant r_{ij}, \tag{1}$$

where r_{ij} represents the cost of moving the good from location i to location j (we will refer to this cost as the transport cost, although it includes all relevant costs of arranging transactions between spatially separate locations). Furthermore, the condition will hold as an equality if there is direct trade between the locations.

For many economists, the spatial arbitrage condition is the starting point for any model of spatial price behavior. It is important to recognize, however, that it is an equilibrium concept. Actual prices may diverge from this relationship but the actions of arbitrageurs will, in a well-functioning market, tend to move the price spread toward the transport cost. It is also important to point out that it is possible to construct equilibrium models that fail to satisfy the spatial arbitrage condition, especially if there are significant delays in transport. The simple statement of the spatial arbitrage condition also hides important details concerning how the price is defined. For example, at any location more than one price may exist due to the existence of a bid/ask spread representing the return to merchandising. In addition, so-called spot prices may actually account for standard delivery lags and hence contain a forward price component. Nonetheless, the spatial arbitrage condition is expected to hold approximately and deviations from it should be of a transitory nature.

2.2. The Law of One Price

The Law of One Price (LOP) holds that, abstracting from transactions costs, regional markets that are linked by trade and arbitrage will have a common, unique price. The LOP has a long tradition in economics. Marshall (1890, p. 325) wrote that "... the more nearly perfect a market is, the stronger is the tendency for the same price to be paid for the same thing at the same time in all parts of the market".[2] The fact that this concept is denoted to be a "law" reflects the considerable faith placed in its adherence.

[2] Marshall (1890, p. 325) went on to note the importance of transactions costs in stating that "... but of course, if the market is large, allowance must be made for the expense of delivering the goods to different

In spite of this prominence, there are actually several different versions of this "law". On the one hand, some people do not distinguish between the LOP and the spatial arbitrage condition. We will refer to this view as the "weak" LOP. A stronger version of the LOP is that the spatial arbitrage condition holds as an equality (the presumption being that trade is continuous). An aggregate version of the LOP, stated in terms of price indices, is known as Purchasing Power Parity (PPP). The assumptions needed for PPP to hold are far more restrictive than for the LOP, even if PPP is applied only to bundles of traded goods.

It is the strong form of the LOP that is often tested; hence such tests must be interpreted not so much as tests of equilibrium conditions as tests that are conditional on assumptions regarding trade linkages. To emphasize the point, violations of the strong form of the LOP may indicate a lack of a stable trading relationship or a disequilibrium situation (or both).

2.3. Spatial market integration

Spatial market integration is a term whose meaning is even less agreed-upon than the LOP. In general, market integration refers to a measure of degree rather than a specific relationship. At one extreme are completely separated markets and at the other are perfectly integrated markets, which should exhibit the strong form of the LOP. To add to confusion, however, the term market integration is often used to refer to perfect market integration, and even to the weak form of the LOP (i.e., to the spatial arbitrage condition).

We adopt the view that the market integration is a distinct concept from the absence of arbitrage. Early usage of the term defined integration as the degree of co-movement of prices in different locations, specifically as measured by the correlation between the prices. Price co-movement for a given commodity can arise, however, for many reasons that have nothing to do with whether a trading network in the commodity links the regions. Furthermore, prices that satisfy the strong form of the LOP may not move together if transport costs are large and volatile.

Although no completely satisfactory definition has appeared in the literature, we propose that market integration is best thought of as a measure of the degree to which demand and supply shocks arising in one region are transmitted to another region. Consider a hypothetical shock, ε_A, that shifts the excess demand for a good in region A but not in region B. The price transmission ratio associated with this shock is

$$R_{AB} = \frac{\partial p_B / \partial \varepsilon_A}{\partial p_A / \partial \varepsilon_A}. \tag{2}$$

We take market integration to be a measure of the expectation of the price transmission ratio. Perfect market integration is said to occur if the expected price transmission ratio

purchasers; each of whom must be supposed to pay in addition to the market price a special charge on account of delivery".

is 1. Notice that the ratio may not be symmetric (i.e., $R_{AB} \neq R_{BA}$), so that it is possible for one region to be more integrated with another region than is the other with it.

It is not necessary for two regions to be direct trading partners for a high degree of integration to be present. What is important is that the regions are part of a common trading network. Price shocks may therefore be transmitted indirectly through the network via the trading linkages that connect the regions. For example, if locations A and B are both regular suppliers to location C, they may be integrated just as strongly as if they were direct trading partners.

It is important, however, to distinguish between the term market integration and other forms of integration. For example, regions can be "economically integrated" in the sense that there are no border restrictions restricting the flow of goods, but not be integrated in terms of any specific market. For example, a highly perishable crop may be produced only for local consumption. The market for this good is not integrated because the cost of moving the good between locations is prohibitive. Economic integration may cause price co-movement, however, even among regions that have a low degree of market integration in a specific commodity [Harriss (1979)]. This is also true of regions that share common climatic conditions (a non-economic form of integration).

It is useful to point out that perfect market integration and the strong form of the LOP, as defined here, are distinct concepts. It is possible, for example, that the LOP holds even though regions have price transmission ratios of less than 1 (see Section 3 for some examples). On the other hand, unit price transmission ratios typically imply the strong form of the LOP. This leads to the following hierarchy of measures. Perfect market integration implies the strong form of the LOP which, in turn, implies the weak form of the LOP. Put in an equivalent form:

$$\text{Perfect Market Integration} \Rightarrow \text{Strong Form LOP} \Rightarrow \text{Weak Form LOP}.$$

Weaker and less restrictive notions of market integration are also present in the empirical literature. The recent literature has shown greater awareness of dynamic elements of price adjustment and spatial price linkages. A less restrictive notion of market integration acknowledges that short-run price differences may exist but that, in the long run, one-to-one correspondence of price changes across regional markets should exist. Tests also have been conducted for the lack of integration. Two markets for which there is no transmission of shocks can be said to be non-integrated or separated.

2.4. Spatial market efficiency

Market efficiency is a term even less clearly defined in the literature and one that encompasses a number of distinct concepts. In some studies it is taken as synonymous with the spatial arbitrage condition. Clearly regional or international markets characterized by arbitrage opportunities can be considered inefficient. However, markets should produce prices that accurately reflect all available information about demand and supply conditions as well as transactions costs.

The concept of spatial market efficiency can also encompass an assessment of the size of the transactions costs of trade. These costs may be excessively high for a variety of reasons that are beyond the power of individuals to influence. This is especially true in developing countries, where transactions costs can be high because of poor contract enforcement, inadequate police protection, corruption, excessively high taxes, and inadequate transport and communications infrastructure. Thus market efficiency can entail considerations beyond whether individuals are responding rationally to financial incentives.

Notions of market efficiency are usually used to motivate empirical studies of market integration. This is true in spite of the fact that a common, universally accepted definition of market efficiency is elusive. In general, efficiency is usually meant to imply that the allocation of resources is such that aggregate welfare cannot be further improved upon through a reallocation of resources. In terms of spatial arbitrage, market efficiency is usually interpreted as implying that no opportunities for certain arbitrage profits have been left unexploited by spatial traders.

An interesting observation, however, is that published empirical studies typically reject efficiency, whether the test is conducted in terms of spatial, temporal, or market form dimensions. An alternative interpretation of such empirical conclusions is certainly possible, however, and may be preferable to rejections of conditions implied by theory. If one takes, as a maintained hypothesis, the general notion of market efficiency, then empirical observations inconsistent with efficiency are better interpreted as reflecting the limitations of the modeling approach or specification used in the empirical tests. For example, because data on transactions costs are often difficult to obtain, it is often assumed that transportation costs are stationary around a proportional constant of output prices. If such an assumption is incorrect, one may find that logarithmic price differences are nonstationary, and thus may conclude that spatial price linkages reflect inefficiencies in the market when, in fact, it is the assumptions used in formulating the empirical model that are flawed.

Roll (1979) was one of the first to explicitly discuss the implications of efficient commodity markets for spatial price linkages, though the fundamental idea of efficiency certainly is implicit in much of the early work on market integration. Roll examined aggregate price linkages in international markets, though the concepts are entirely equivalent (and perhaps more appropriate) to considerations of spatial trade in a single commodity among regional markets.

Buccola (1989) discussed the general notion of price efficiency. He noted that "efficiency" in prices corresponds to the set of prices that result in an optimal (efficient) allocation of resources. This optimum is described as the allocation of resources that maximizes individuals' utilities of output, conditional on the available stock of resources. In addition, he notes that tests of spatial efficiency are typically based upon the augmenting hypothesis that markets are "efficient" (in terms of maximizing utility of output) in time and form domains. Buccola stresses the role of agents' costs in market efficiency studies and points out that some short-run inefficiencies may be optimal if their elimination requires large capital investments. He notes that price differences are often taken to represent transactions costs and also points out that, given the difficulty in measuring agents' marketing costs, "the potential for circularity in efficiency research is great".

The most important point to emerge from a consideration of the terminology and definitions that characterize the extensive literature on spatial market integration is that common definitions of arbitrage, efficiency, and integration do not exist. Different authors invoke different definitions of these concepts and their empirical tests therefore involve different hypotheses about the market conditions implied by integration. The literature must be examined with careful attention to the specific conditions being evaluated and used to construct empirical tests. Evidence consistent with one author's view of integration might be taken as evidence against integration by another.

3. Economic models of price determination

A variety of models have been used to examine the behavior of spatial prices. These models are categorized by two distinguishing features. The first concerns the nature of dynamics used in the model. The most common approach to modeling spatial prices is based on one of several static spatial equilibrium models. Prices change over time due to exogenous shifts in model parameters; this results in a sequence of static equilibria. Other models incorporate dynamic relationships directly into the equilibrium model. For example, endogenous dynamics arise due to storage and temporal delays in arranging sales and in delivery. Although such models are more general in that they endogenize dynamics, they also tend to be more difficult to solve.

A second distinguishing feature concerns the nature of spatial arrangements. In the most general sense, spatial economic activity can be viewed as occurring over a two-dimensional continuum. Indeed, many early models of spatial activity took this view. Recently, however, network models consisting of a set of points or nodes connected by links over which commodities or people travel have been more the norm. Network models can be distinguished according to whether the links are used solely for the purpose of moving goods among the nodes or whether other activities occur along the links. We will refer to the former as point-location models and the latter as agents-on-links models.

3.1. Models with exogenous dynamics

3.1.1. Point-location models

The simplest model of spatial price determination is the static point-location model first discussed by Enke (1951) and Samuelson (1952) and extensively developed by Takayama and Judge (1964a, 1964b, 1971); a more recent discussion is Thompson (1989). Point-location models are appropriate for markets in which the nodes represent major collection, processing or distribution centers that deal directly with one another.

For example, the grain market in the United States includes a system of terminal elevator locations on major water and rail links. A study of prices at these locations could be appropriately modeled with a point-location model.

The basic n-location model can be easily described. It is characterized by an excess demand function

$$q = D(p) \tag{3}$$

that relates the excess amount demanded, q (an n-vector), to the price vector, p, and a matrix of constant marginal transport rates, with r_{ij} representing the cost of transporting one unit of the commodity from location i to location j. Two conditions characterize the equilibrium, the Law of One Price,

$$p_i - p_j + r_{ij} \geqslant 0, \quad s_{ij} \geqslant 0, \quad s_{ij}(p_i - p_j + r_{ij}) = 0 \tag{4}$$

(where s_{ij} is the amount shipped from location i to j) and an accounting identity that relates the excess demand to the shipment amounts,

$$q_i = D_i(p) = \sum_{j=1}^{n} s_{ji} - s_{ij}. \tag{5}$$

Inverting the D_i allows the LOP condition to be stated in terms of the shipment amounts alone:

$$\begin{gathered} D_i^{-1}\left(\sum_{j=1}^{n} s_{ji} - s_{ij}\right) - D_j^{-1}\left(\sum_{j=1}^{n} s_{ji} - s_{ij}\right) + r_{ij} \geqslant 0, \quad s_{ij} \geqslant 0, \\ s_{ij}\left(D_i^{-1}\left(\sum_{j=1}^{n} s_{ji} - s_{ij}\right) - D_j^{-1}\left(\sum_{j=1}^{n} s_{ji} - s_{ij}\right) + r_{ij}\right) = 0. \end{gathered} \tag{6}$$

The equilibrium conditions can therefore be written in the form

$$f(x) \geqslant 0, \quad x \geqslant 0, \quad x^{\mathrm{T}} f(x) = 0, \tag{7}$$

a condition known as a complementarity problem.

The model can easily be generalized in several ways. First, the transport rates could be responsive to the shipment levels: $r = T(S)$, where r is the vector of transport rates and S the vector of commodity shipments. Second, multi-commodity and intertemporal systems could be developed by interpreting "location" to represent specific space/time/form characteristics. With the "transport" cost matrix represented by appropriate transformation cost functions, the basic form of the model remains the same. For example, costs of storage backwards in time are made arbitrarily large and therefore infeasible.

Much effort has been devoted to the development of efficient algorithms to solve such problems. In some cases it is possible to cast the problem as an optimization exercise. Specifically, if the Jacobian of D is symmetric (implying integrability of the excess demand function), there is an equivalent optimization problem associated with the competitive equilibrium. Takayama and Judge exploited this relationship in models with linear demand functions, showing that the equilibrium could be solved as a quadratic programming problem. An alternative approach was developed by Tramel and Seale (1959), with improvements by King and his associates [King (1963), King and Ho (1972)]. The so-called reactive programming algorithm allocated fixed quantities using a least-cost linear programming algorithm and then iteratively adjusted those quantities to ensure that prices satisfied arbitrage constraints. In recent years there have been significant improvements in algorithms for solving linear and non-linear complementarity problems, as well as related variational inequality problems. Large-scale complementarity problems can now be routinely solved using widely available software [Ferris and Pang (1997), Billups et al. (1997)].

3.1.2. Agents-on-links models

The point location model is a network model with the links between network nodes used only for commodity transport. Another important class of spatial network models has individual agents producing or consuming along the links, and with network nodes representing market centers. This framework has been widely used to study spatial competition among oligopolistic firms located at nodes, which compete for the business of agents on the links [see, for example, Faminow and Benson (1990)]. It has also been used to model competitive markets with nodes representing central markets where spatially dispersed producers transport and sell their goods [Dahlgran and Blank (1992)].

From a theoretical point of view, such agents-on-links models can be viewed as continuous extensions of the point-location model. As the nodes in a point-location model become dense, the model mimics the agents-on-links model. Therefore, one should expect that theoretical results applying to one model should be obtainable from the other. Some results, however, are more easily obtained using one or the other formulation and, in empirical work, one or the other will generally be a natural representation of a specific market.

3.1.3. Dynamic linkages

With either model type, an important issue concerns dynamic linkages. Linkages involving a time dimension occur for a variety of reasons including storage, transport delays, investment, seasonality (in production and consumption), demographic shifts, preference shifts, etc. With the exception of storage and transport delays (and possibly investment), price analysts generally treat these factors as exogenous and represent them as shifts in regional demand and supply functions. By treating dynamics as exogenous, equilibrium prices are determined by a sequence of static equilibria. Such models are therefore termed "sequential equilibrium models". To illustrate how spatial price analysis is conducted using network models and to examine some of the implications of these models, we use a simple two-location model with linear excess demands. The basic conclusions, however, extend to more general models.

The first model is a point-location model with linear excess demand functions that depend only on the home price. At time t, the location i excess demand function is

$$q_{it} = b_i(a_{it} - p_{ti}), \tag{8}$$

where q_{it} is the net imports (exports if negative), p_{it} is the price, and a_{it} is an exogenous shock that causes parallel shifts in excess demand. Assume that the per unit transport costs, denoted by r_{ijt}, are exogenous (i.e., their value does not depend on conditions in the commodity market).

The equilibrium conditions for such a model are that

$$-b_1(a_1 - p_1) = b_2(a_2 - p_2) \quad \text{and} \quad -r_{12} \leqslant p_1 - p_2 \leqslant r_{21} \tag{9}$$

with first (second) inequality holding exactly if $s_{12} > 0$ ($s_{21} > 0$). The first condition is a material balance equation, the second is the spatial arbitrage condition. Taken together these define a functional relationship between the four exogenous variables (a_{1t}, a_{2t}, r_{12t}, and r_{21t}) and the endogenous prices and shipment amounts.[3]

A sequential equilibrium model imposes the static equilibrium conditions at each point in time. Serial correlation in prices in sequential equilibrium models arises from the exogenous serial correlation of the exogenous variables (the excess demand shifters and transport costs). If these exogenous variables are serially independent, then prices will be as well. Generally, however, these variables will exhibit significant serial correlation; indeed they may exhibit long-run persistence (unit roots).

The natural occurrence of serial correlation in the shocks implies that the kind of informational efficiency tests developed for speculative asset markets may be improperly applied to commodity prices. Informational efficiency tests are usually based on a presumed lack of intertemporal arbitrage opportunities, a condition which often rules out serial correlation in returns. These tests are properly applied to excess returns on speculative assets which should be essentially unpredictable in an informationally efficient market because predictable excess returns would imply the existence of expected excess

[3] The explicit solution for prices is:

$$\left.\begin{aligned} p_1 &= \omega_1 a_1 + \omega_2 a_2 - \omega_2 r_{12} \\ p_2 &= \omega_1 a_1 + \omega_2 a_2 + \omega_1 r_{12} \end{aligned}\right\} \text{ if } a_1 - a_2 \geqslant r_{12}, \qquad \left.\begin{aligned} p_1 &= a_1 \\ p_2 &= a_2 \end{aligned}\right\} \text{ if } -r_{21} \leqslant a_1 - a_2 \leqslant r_{12},$$

$$\left.\begin{aligned} p_1 &= \omega_1 a_1 + \omega_2 a_2 + \omega_2 r_{21} \\ p_2 &= \omega_1 a_1 + \omega_2 a_2 - \omega_1 r_{21} \end{aligned}\right\} \text{ if } a_2 - a_1 \geqslant r_{21},$$

where $\omega_i = b_i/(b_1 + b_2)$, for $i = 1, 2$.

profits. Serial correlation in commodity prices, on the other hand, does not imply excess expected profits so long as there are real dynamic links. For example, intertemporal arbitrage in storable commodity markets ensures prices are expected to rise enough to cover storage costs, implying a high degree of serial correlation in prices. Indeed, the lack of serial correlation would be a sign of a malfunctioning market.

The dynamics of price behavior, even in the simplest spatial equilibrium model, can be quite complicated. In the model with two locations, qualitatively different behavior occurs in each of three possible regimes. Which regime occurs depends on the relative sizes of the reservation or autarky prices (the a_i) and the transport rates (in a model with more locations, explicit determination of the regime becomes far more burdensome).[4] In markets for which a single regime can be assumed (i.e., the direction of trade flows does not change), the model has strong implications for dynamic price behavior. In particular, if the locations are mutually isolated, shocks arising in one location have no impact on the price in the other location. On the other hand, if the locations do trade, an excess demand shock arising in one location has an equal price impact in both locations.[5] The intuition is that the spread between the prices does not change (it is equal to the transport rate) and therefore both prices must rise or fall by equal amounts. It is precisely this feature that is used to justify much of the empirical analysis of spatial price relations.

Unfortunately, the simple point-location model is a poor description of many spatial market structures and has a number of limitations. Although not relevant in a two-location model, multi-location versions result in, at most, a single route being used to connect any two locations. This rules out situations such as two deficit regions both being supplied by the same two surplus regions, or cases of goods moving between two locations via two or more transshipment regions. As a predictor of actual trade flows, the simple point-location model is extremely limited.

Furthermore, using price transmission ratios as a measure of market integration, the simple point-location model imposes the condition that, at a given time, any two locations are either fully integrated or are mutually isolated. There is, therefore, no possibility for partial integration unless the trading regime changes (e.g., if an exporting region becomes an importing region).

One way to address these concerns is with a model in which transport rates tend to rise as transport services are more heavily used. Consider the case in which location 1 ships to location 2 and the transport rate is a linear function of the amount shipped: $r_t = \rho_t + \phi s_{12t}$, where s_{12t} is the quantity shipped from location 1 to 2. The equilibrium arbitrage relationship for this market is

$$p_{2t} - p_{1t} = \rho_t + \phi s_{12t} \tag{10}$$

and the market-clearing condition requires that

$$s_{12t} = b_2(a_2 - p_2) = -b_1(a_1 - p_1). \tag{11}$$

[4] See McNew and Fackler (1997) for the explicit solution in the three-location case.

[5] This observation applies in multi-location models as well.

These conditions can be solved to express the two prices as functions of the underlying parameters:

$$
\begin{aligned}
p_t &= \frac{1}{b_1 + b_2 + \phi b_1 b_2} \begin{bmatrix} b_1 + \phi b_1 b_2 & b_2 & b_1 \\ b_1 & b_2 + \phi b_1 b_2 & b_2 \end{bmatrix} \begin{pmatrix} a_{1t} \\ a_{2t} \\ \rho_t \end{pmatrix} \\
&= \begin{bmatrix} \omega_1 a_{1t} + (1 - \omega_1) a_{2t} + (\omega_1 - 1) \rho_t \\ (1 - \omega_2) a_{1t} + \omega_2 a_{2t} + (1 - \omega_2) \rho_t \end{bmatrix},
\end{aligned}
\tag{12}
$$

where $0 < \omega_i < 1$ and $\omega_1 + \omega_2 > 1$.

Three important implications for price behavior are implied by this model. First, shifts in the excess demand functions (i.e., changes in a_i) have a greater impact on the price in the location where they occur than in the other location:

$$
1 - \omega_i = \frac{\partial p_{it}}{\partial a_{jt}} < \frac{\partial p_{jt}}{\partial a_{jt}} = \omega_j. \tag{13}
$$

Thus a shock originating in one location is not fully transmitted to the other location. Instead, some of the shock is absorbed by changes in the transport rate. Second, a shift in the supply of transport services is not fully absorbed by the commodity price changes:

$$
\frac{\partial (p_{2t} - p_{1t})}{\partial \rho_t} = \frac{b_1 + b_2}{b_1 + b_2 + \phi b_1 b_2} < 1. \tag{14}
$$

Some of the supply shift is absorbed by the carrier in the form of reduced shipments. The price differences can be written as a weighted sum of the transport rate shock and the difference in the excess demand shocks:

$$
p_{2t} - p_{1t} = \lambda \rho_t + (1 - \lambda)(a_{2t} - a_{1t}), \tag{15}
$$

where $\lambda = (b_1 + b_2)/(b_1 + b_2 + \phi b_1 b_2)$, implying that $0 \leqslant \lambda \leqslant 1$.

The third implication is that there are more sources of market shocks than there are variables in the model. In the simpler model, the effect of an excess demand shock is the same regardless of its origin and hence aggregation of these shocks is possible. With quantity responsive transport rates, however, it is not possible to associate the effects of the price prediction errors (innovations) with specific sources. This complicates meaningful inferences regarding pricing efficiency using only price data.

Similar conclusions must be reached in the context of agents-on-links models. Consider a situation [as in Dahlgran and Blank (1992)] in which producers are located in rural areas and have a choice about where to market their goods. To examine this in the context of an agents-on-links model, suppose there are two demand centers and producers are evenly distributed along the transport link between the centers. Production in each period is an exogenously determined amount s_t. Each of the demand centers has downward-sloping demand $q_{it} = b_i(a_{it} - p_{it})$. The distance between the centers is normalized to equal 1 and the transport cost per commodity and distance unit is r_t. If this market is integrated and in equilibrium, it satisfies the following set of conditions:

$$b_1(a_{1t} - p_{1t}) + b_2(a_{2t} - p_{2t}) = s_t \quad \text{(market clearing)}, \tag{16}$$

and

$$p_{1t} - r_t B_t = p_{2t} - r_t(1 - B_t) \quad \text{(no spatial arbitrage)}, \tag{17}$$

where B_t is the distance from location 1 of the producer who is indifferent between selling in locations 1 and 2. In this simple model, B_t is also the share of the production sold in location 1:

$$B_t = \frac{q_{1t}}{s_t}. \tag{18}$$

Solving these conditions for prices yields:

$$\begin{aligned}\begin{bmatrix} p_{1t} \\ p_{2t} \end{bmatrix} &= \frac{1}{(b_1 + b_2)s_t + 2b_1b_2r_t} \begin{bmatrix} (b_1a_{1t} + b_2a_{2t} - s_t)s_t - b_2(2b_1a_{1t} - s_t)r_t \\ (b_1a_{1t} + b_2a_{2t} - s_t)s_t - b_1(2b_2a_{2t} - s_t)r_t \end{bmatrix} \\ &= \begin{bmatrix} \omega_{1t}a_{1t} + (1 - \omega_{1t})a_{2t} - \dfrac{1 + b_2z_t}{b_1 + b_2 + 2b_1b_2z_t} s_t \\ (1 - \omega_{2t})a_{1t} + \omega_{2t}a_{2t} - \dfrac{1 + b_1z_t}{b_1 + b_2 + 2b_1b_2z_t} s_t \end{bmatrix},\end{aligned} \tag{19}$$

where $z_t = r_t/s_t$ and $\omega_{it} = (b_i + 2b_1b_2z_t)/(b_1 + b_2 + 2b_1b_2z_t)$. The equilibrium prices are weighted averages of the reservation prices less a term that increases with the amount produced. The sizes of the weights vary over time (with z_t) as does the coefficient on the s_t term. To the extent that z_t is stable over time, this yields an equilibrium that is linear in three exogenous variables, the two demand reservation prices a_i and total production s_t.[6]

The agents-on-links model has features similar to that of the point-location model with upward-sloping transport supply. In particular, a shock originating in one location (a_i) has a larger price effect at home than at the other location ($(1 - \omega_j) < \omega_i$). Furthermore, price differences are functions of all of the shocks:

[6] The stability of z_t is an empirical matter. It will be stable if transport rates increase proportionally with production and hence with the amount transported. It should also be noted that this model takes no account of the possibility of regime shifts that would arise if transport rates became low relative to the price. It would then be possible that some producers would elect to not ship at all because the price they receive, net of transport costs, would be negative.

$$p_{2t} - p_{1t} = \frac{2b_1b_2z_t}{b_1 + b_2 + 2b_1b_2z_t}(a_{2t} - a_{1t}) + \frac{b_2 - b_1}{b_1 + b_2 + 2b_1b_2z_t} r_t. \tag{20}$$

In the simple point-location model, the nature of price adjustment to shocks originating in one of the locations is quite simple. If the locations are linked by trade, both prices adjust equally; otherwise there is no adjustment. In slightly more complicated models, however, marginal adjustments can occur, so the adjustments can lie somewhere between all and nothing. Furthermore, price differences are not associated just with transport rate changes. How important such effects are has not been examined empirically.

The models discussed in this section have important implications for the interpretation of econometric analyses of spatial price behavior. With three (or more) interpretable sources of randomness (excess demand shocks in each region and transport rates) and only two observable prices, the effects of the demand and supply shocks cannot be identified. Furthermore, there is no expectation that a shock originating in one location will have the same effect on both prices. In general, shocks originating in one location have a larger price effect there than in the other location, so the transmission of shocks is less than complete. Even if the LOP holds strongly, the regions are less than perfectly integrated. The meaning of tests based on price co-movements will, therefore, need to be interpreted cautiously.

It should also be emphasized that the analysis of the effects of shocks here is local only (i.e., it applies only to small shocks). Large shocks have the potential to change the trading patterns among regions, which tends to reduce the degree to which shocks are transmitted, relative to markets with stable trade linkages.

3.2. Models with endogenous dynamics

In the spatial price determination models thus far examined, the nature of intertemporal linkages was essentially ignored. This may be appropriate when the shocks that affect a specific market truly arise beyond that market. For example, weather and fuel price variation fall into this category, as do shocks arising from macroeconomic events. There are other sources of intertemporal price linkages that are more closely tied to a particular market and may result in specific patterns of price variation that should be accounted for, even if spatial interactions are the primary focus of the analysis. One, in particular, is examined here: the effects of delivery lags. Similar conclusions can be reached using models with storage and trade [Williams and Wright (1991)].

To illustrate the problems raised by delivery lags, consider a very simple two-period, two-region model. Suppose that region 1 is a deficit region and 2 a surplus region, that it takes one period to deliver goods from 2 to 1, and that there is no forward pricing mechanism.[7] Further, suppose that excess demand shocks in region 1 exhibit first order serial correlation:

$$a_{1t} = \rho a_{1t-1} + v_{1t}. \tag{21}$$

[7] We assume that any shocks to the market are never large enough to change the import/export status of the two regions.

A positive value of v_{1t} will induce region 2 to ship more now, in order to respond to the higher demand in region 1 in the next period. In fact, other things being equal, we would expect that the period t price in region 2 should shift up by the same amount that region 1's price is expected to rise in the next period:

$$\frac{\partial p_{2t}}{\partial v_{1t}} = \frac{\partial \operatorname{E}[p_{1t+1}]}{\partial v_{1t}} = \rho < 1. \tag{22}$$

In the first period, however, region 1 must absorb the whole shock, so

$$\frac{\partial p_{1t}}{\partial v_{1t}} = 1. \tag{23}$$

This implies a price transmission ratio from 1 to 2 arising from region 1 demand shocks of less than one:

$$\frac{\partial p_{2t}/\partial v_{1t}}{\partial p_{1t}/\partial v_{1t}} = \rho < 1. \tag{24}$$

Again, even in a simple model, it is not unusual to obtain a result in a well-functioning market that the price transmission ratio is less than one.

The problem is more fundamental, however. Consider a situation in which excess demands in the two regions are given by

$$q_{it} = b_i(a_i + v_{it} - p_{it}) \tag{25}$$

for $i = 1, 2$, where the v_i are i.i.d. white noise processes. As before, it takes one period to ship from region 2 to 1 at a cost of r_t. The lack of persistence in the noise processes means that the amount shipped bears no relationship to the shock in the importing region.[8] Although the price in region 2 will vary with v_{2t} and r_t, it is unaffected by the

[8] The equilibrium conditions for this model are

$$p_{2t} + r_t = \delta \operatorname{E}_t[p_{1t+1}],$$

where $0 < \delta < 1$ is a discount factor, and

$$q_{1t+1} = -q_{2t}.$$

The equilibrium prices can be shown to satisfy

$$\delta P_{1t} = \delta\omega_1 a_1 + \omega_2(a_2 + v_{2t-1}) + \omega_2 r_t + \delta v_{1t}, \quad P_{2t} = \delta\omega_1 a_1 + \omega_2(a_2 + v_{2t-1}) - \omega_1 r_t,$$

where $\omega_1 = b_1/(b_1 + \delta b_2)$ and $\omega_2 = \delta b_2/(b_1 + \delta b_2)$. It can be readily verified that ratio of the effect of v_{2t} on the discounted importing price next period, δp_{1t+1}, is equal to the effect of v_{2t} on p_{2t} (essentially a discounted version of perfect price transmission). However, the effect of v_{1t} on p_{1t} is 1, whereas its effect on p_2 (at any time horizon) is 0. There is, therefore, an asymmetry in the effects of shocks in shipping and receiving regions.

magnitude of v_{1t}. The price transmission ratio from 1 to 2, therefore, is 0, even though the regions are well connected (trading every period). The shipping delay creates a situation in which there is no transmission of shocks from 1 to 2. Furthermore, although shocks in region 2 do affect the price in region 1, they do so only at a lag and the instantaneous transmission is zero. It should be noted, however, that a permanent shift in excess demand, i.e., a shift in a_1 or a_2, is perfectly transmitted (when appropriately discounted), with shifts in a_1 having an immediate impact, and shifts in a_2 impacting region 1 one period later.

This suggests the need for a more dynamic approach to understanding market integration. Two points are in order. First, the speed with which shocks are transmitted will clearly depend upon response delay times. Second, the persistence of the shocks in the receiving regions interacts with the shipping delays to determine the degree to which the shipping regions will respond. More fundamentally, this example points out that the use of price variation, which is essentially the foundation of all empirical analyses of the LOP and market integration, can fail in the presence of shipping delays. In our simple example, the markets were integrated in the sense that they are connected by trade and by the fact that shipping region shocks were transmitted, but failed to be integrated in the sense that importing region shocks are translated forward. To date, the asymmetry of forward and backward linkages has not been addressed.

4. Empirical tests

In this section we provide a framework for understanding the numerous empirical studies of spatial price behavior. Most of the studies mentioned and many not explicitly referenced are listed in Table 1, along with their publication date, the commodity and country examined, and the main methodology used. These methodologies include simple regression and correlation analyses as well as a number of methods based on vector autoregressions and related approaches such as Granger-causality and cointegration analyses. More recent switching regime approaches are also discussed.

4.1. Simple regression and correlation analysis

Many early empirical studies of market integration, especially those applied to agricultural markets in developing countries, appealed to the simple idea that prices in spatially linked markets should be highly correlated. Perhaps the first study to make use of correlation analysis to evaluate market integration is the analysis of Punjab wheat prices by Mohendru (1937).

Mohendru reported pairwise correlation coefficients ranging from 0.43 to 0.86 for fortnightly prices observed over a period of six months at four important Punjab wheat markets. Jasdanwalla (1966) evaluated spatial linkages using monthly groundnut prices for terminal and local markets in India. He found that correlation coefficients were stronger among terminal markets than between terminal and local markets. Two early

Table 1
A summary of empirical dynamic spatial price analyses

Authors	Date	Location	Product	Method of analysis
Adamowicz, Baah and Hawkins	1984	Canada	Hogs	Granger causality
Alderman	1993	Ghana	Grains	Ravallion /Cointegration
Alexander and Wyeth	1994	Indonesia	Rice	Cointegration
Ardeni	1989	International	*	Cointegration
Baffes	1991	International	*	Cointegration
Baulch	1994	Philippines	Rice	Switching regime
Benson and Faminow	1990	Canada	Hogs	Granger causality
Benson, Faminow and Fik	1992	Canada	Hogs	Ravallion
Benson, Faminow, Maquis and Sauer	1994	Canada	Hogs	Cointegration
Bessler and Fuller	1994	U.S.	Wheat	Cointegration
Blank and Schmiesing	1988	U.S.	Corn	Granger causality
Brorsen, Chavas, Grant and Ngenge	1985	U.S.	Grains	Impulse analysis /Granger causality
Cummings	1967	India	Wheat	Correlation
Currie	1995	U.S.	Petroleum	Switching regime
Dahlgran and Blank	1992	U.S.	Hay	Ravallion
Dercon	1995	Ethiopia	Teff	Cointegration
Dries and Unnevehr	1990	International	Beef	Granger causality
Ejiga	1977	Nigeria	Cowpeas	Correlation
Faminow and Benson	1990	Canada	Hogs	Ravallion
Goletti	1994	Bangladesh	Rice	Cointegration /Multipliers
Goletti and Babu	1994	Malawi	Maize	Cointegration /Impulse analysis
Goletti and Christina-Tsigas	1995	**	Rice/Maize	Multipliers
Goodwin	1992	International	Wheat	Cointegration
Goodwin and Grennes	1998	International	Wheat	Switching regime
Goodwin, Grennes and McCurdy	1999	Russia	***	Impulse analysis
Goodwin and Schroeder	1991	International	Wheat	Impulse analysis
Goodwin and Schroeder	1991	U.S.	Cattle	Cointegration
Gordon, Hobbs and Kerr	1993	Britain/France	Lamb	Granger causality
Gupta	1973			Correlation
Gupta and Mueller	1982	Germany	Hogs	Granger causality
Heytens	1986	Nigeria	Gari and yams	Timmer
Higginson, Hawkins and Adamowicz	1988	Canada/U.S.	Hogs	Granger causality /Impulse analysis
Jasdanwalla	1966	India	Groundnuts	Correlation
Jordan and Van Sickle	1995	U.S./Mexico	Tomatoes	Ravallion /Granger causality
Klein, Rifkin and Uri	1985	U.S.	Flour	Granger causality
Koontz, Garcia and Hudson	1990	U.S.	Cattle	Granger causality
Lele	1967	India	Sorghum	Correlation
Loveridge	1991	Rwanda	Dry Beans	Correlation
Lutz, Van Tilburg and Van Der Camp	1995	Benin	Maize	Cointegration /Ravallion

Table 1
(Continued.)

Authors	Date	Location	Product	Method of analysis
Mendoza and Rosegrant	1992	Philippines	Corn	Granger causality
Mendoza and Rosegrant	1995	Philippines	Corn	Granger causality /Multipliers
Mendoza and Rosegrant	1995	Philippines	Copra	Granger causality /Ravallion
Michael, Nobay and Peel	1994	International	Wheat	Cointegration
Mjelde and Paggi	1989	U.S.	Corn	Impulse analysis
Mohendru	1937	India	Wheat	Correlation
Palaskas and Harriss-White	1993	India	****	Cointegration
Prakash	1996	India	Rice	Switching regime
Ravallion	1986	Bangladesh	Rice	Ravallion
Sexton, Kling and Carman	1991	U.S.	Celery	Switching regime
Silvapulle and Jayasuriya	1994	Philippines	Rice	Cointegration
Slade	1986	U.S.	Petroleum	Granger causality
Spiller and Huang	1986	U.S.	Gasoline	Switching regime
Spiller and Wood	1988	U.S.	Gasoline	Switching regime
Teklu, von Braun and Zaki	1991	Sudan	Sorghum/cattle	Timmer
Thompson, Eales and Hauser	1990	U.S.	Grains	*****
Timmer	1987	Indonesia	Corn	Timmer
Tschirley	1995	Ecuador	Maize	Timmer
Uri, Chomo, Hoskin and Hyberg	1993	International	Soy	Granger causality
Uri, Howell and Rifkin	1985	U.S.	Flour	Granger causality
Webb, von Braun and Yohannos	1992	Ethiopia	Grains	Timmer
Williams and Bewley	1993	Australia	Cattle	Impulse analysis

* Wheat, wool, beef, sugarcane, tea, tin, zinc.
** Bangladesh rice and Malawi maize.
*** Eggs, milk, vegetable oil, potatoes.
**** Rice, potatoes, mustard.
***** Uses a spatial basis regression model.

studies of integration of Indian grain markets were presented by Cummings (1967) and Lele (1967). Both authors found correlation coefficients ranging from 0.65 to 0.9 and thus concluded that markets were highly integrated. A number of other similar studies [see, for example, Gupta (1973) and Ejiga (1977)] have used spatial price correlation coefficients to evaluate market integration.

A shortcoming of such an approach to empirical testing of market integration involves the influences of common components such as inflation, population growth, or climate patterns that affect all markets, regardless of the extent to which the markets are linked through trade in a specific commodity. Correlation in such cases may be of a spurious nature and may not reflect what one commonly assumes to be the implications of spatially integrated markets. Harriss (1979) notes this problem and points out that the extent to which individual price series are aggregated over time may affect the extent to which these systemic effects are problematic. In particular, she argues that more finely sampled data are likely to be more revealing of the actions of traders rather than simply reflecting the systemic influences of aggregate factors. Blyn (1973) noted this limitation and recommended regressing raw price series on such systemic factors and using the resulting residuals to perform correlation tests. Such an approach, though statistically inefficient, can provide consistent estimates of correlation coefficients that are not subject to the spurious correlation effects, although one must be able to quantify and accurately measure the systemic factors in order to implement such a test. In tests using daily or weekly prices, such factors may be impossible to measure.

Harriss (1979) discussed a number of other shortcomings inherent in the price correlation coefficient approach to testing spatial market integration. She notes that monopoly procurement at fixed prices will yield correlation coefficients of 1.0, regardless of the actual degree of interaction between individual regional markets. Of course, the extent to which such a criticism damages the credibility of an empirical test depends upon one's definition of integration. A monopoly procurement agency that buys at identical prices from different regional markets may be interpreted as a strong mechanism for integrating markets, albeit in a noncompetitive environment. Harriss also points out the basic problems inherent in empirical tests arising because of heterogeneous goods, uncertainty, and inaccurate and missing price data. Such limitations are obviously important and are applicable to any empirical test of market integration.

Another shortcoming associated with the use of the correlation coefficient as an instrument for measuring integration between two markets involves the potential for independent variation of prices within the margin or band created by transactions costs. Indeed, many of the early authors seem aware of such limitations and attribute correlation coefficients that are far from 1 to transportation costs, bottlenecks, and uncertainty [see, for example, Cummings (1967) and Lele (1971)]. It is easy to show that any value of a correlation coefficient can be consistent with spatially integrated markets if transactions costs are large enough to prohibit profitable trade and thus permit independent variation of price differences within the transactions cost band. This general idea is not new [e.g., Adler and Lehmann (1983)], although methods for explicitly recognizing the importance of the transactions costs band have made their way into the empirical literature only in recent years. As will be discussed in detail below, explicit recognition of the transactions cost band requires either direct observation of transactions costs or the adoption of very restrictive assumptions regarding the behavior of transactions costs. Actual measurement of transactions costs is notoriously difficult because even the most basic components of transactions costs (e.g., transportation charges) are typically unknown. In this light, much of the recent research has taken the latter approach, adopting simplistic representations of transactions costs in empirical tests.

Closely related to the idea of correlation analysis is the literature that has implemented regression-based tests of spatial market integration. Indeed, it is straightforward to show that the concepts are nearly identical in terms of the mechanics used to develop empirical tests, though the interpretation of the results is distinctly different.[9] Econometric studies using regression methods do depend upon important causality assumptions both in estimation and in the interpretation of results. Recognition of this joint determination of prices has led researchers to adopt alternative regression methods utilizing instrumental variables techniques to obtain consistent parameter estimates. Unfortunately, many studies do not pay enough attention to issues of model identification and simultaneity, even though market integration may imply that prices are jointly determined.

A distinction between correlation coefficients and simple bivariate regression is also inherent in the approaches taken to inference under the alternative procedures. In small samples, the distribution of the sample correlation coefficient ρ_{12} is difficult to obtain, though adequate approximations are available for reasonably large samples. Inference in a simple regression model is straightforward, providing that causal patterns can be assigned.

Standard bivariate regression tests of spatial integration typically adopt some version of the model introduced by Richardson (1978):

$$P_{1t} = \beta_0 + \beta_1 P_{2t} + \beta_2 T_t + \beta_3 R_t, \tag{26}$$

where P_{it} represents the price in market i, T_t represents transactions cost, R_t represents residual reasons for price differences, and the β_k's are parameters to be estimated. In Richardson's model, cast in the framework of the law of one price, markets are taken to be perfectly integrated if $\beta_1 = \beta_2 = 1$ and $\beta_0 = \beta_3 = 0$. Such models are commonly evaluated in first-differenced or in logarithmic form. In levels or first differences, the coefficient on the price term represents the marginal effect on one price (the dependent variable) of a change in another price. Perfect integration is commonly assumed to imply that this coefficient is 1. If the analysis is conducted using a linear in logarithms specification, the coefficient represents the price transmission elasticity which, again, is assumed to have the value of 1 for perfectly integrated markets. It has been common to allow for fixed (in the linear model) or proportional (in the logarithmic model) differences in prices by relaxing the restriction that the intercept term β_0 must be zero. Such an assumption is often imposed as a crude means for representing transactions costs. In a linear model, it may be assumed that transportation costs have a constant mean and are uncorrelated with either of the prices. In the case of a logarithmic model, it is commonly assumed that transactions costs can be represented as a constant proportion of price and thus can be captured by a constant in the regression model. As a rule, such

[9] In particular, one can note that, for a set of two prices, P_1 and P_2, the correlation coefficient is given by $\rho_{12} = \sigma_{12}/(\sigma_1\sigma_2)$, where σ_{12} is the covariance between the two prices and σ_i is the standard deviation for the price in market i. Likewise, in a regression of the form $P_1 = \alpha + \beta P_2$, the least squares estimate of β is given by σ_{12}/σ_{22}, where σ_{22} represents the variance of P_2. Clearly, $\beta = (\sigma_1/\sigma_2)\rho_{12}$ and thus ρ_{12} and β are proportional and are of the same sign.

models are inherently of a static nature in that arbitrage conditions are assumed to hold contemporaneously and no lags in adjustments are explicitly recognized.

All of the limitations inherent in the simple correlation coefficient approach are equally applicable to the simple regression model. The shortcomings associated with a neglect of transactions costs and price variation within the transactions cost band are especially obvious when the arbitrage condition is expressed in terms of a regression equation. Consider rewriting Equation (26) under the assumptions that the coefficient on the transactions cost term is 1 and the law of one price holds (i.e., that $\beta_1 = \beta_2 = 1$, $\beta_0 = \beta_3 = 0$):

$$P_1 - P_2 = T. \tag{27}$$

The fundamental flaw associated with this regression specification when price variation within a transactions costs band is frequent is the equality that is assumed to hold in the arbitrage condition. In reality, the zero-profit arbitrage condition imposes an inequality in place of the equality:

$$P_1 - P_2 \leqslant T, \tag{28}$$

that is, price differences should be less than or equal to transactions costs. Forcing this condition to hold as an equality in a regression test may result in a serious misspecification error and thus may lead to biases and misleading inferences. The significance of this bias is likely to be determined by the frequency with which price differences are at the boundary of the transactions cost band relative to the frequency that the price differences are within the band.

4.2. Dynamic regression models

Because of the very nature of the price data commonly used to examine spatial price relationships, dynamic time-series analysis techniques are frequently used to evaluate spatial market integration. These tests typically use one or more of the following techniques: Granger causality, dynamic regression tests, impulse response analysis of structural or nonstructural vector autoregressive (VAR) models, and cointegration analysis. The motivation for dynamic tests is obvious in light of the dynamic nature of interregional commodity trade and arbitrage activities. In particular, regionally traded commodities are often bulky and costly to transport and thus regional trade may often involve significant delivery lags and other impediments to adjustment. In this light, adjustments to regional shocks may take several periods to be complete and thus the effects of such shocks may be persistent. In situations where the flow of commodities is unidirectional (for example, from producing to consuming regions), the result of such delivery lags may be lead-lag relationships where price adjustments in one market lag those in another. Serial correlation in the exogenous shocks will also cause persistence in price relationships. Identifying the underlying causes of such persistence (i.e., autocorrelated shocks or delivery lags) may be difficult.

Dynamic regression models typically use some version of a vector autoregression model:

$$A_0 P_t = \sum_{k=1}^{n} A_k P_{t-k} + DX_t + e_t, \tag{29}$$

where P_t is a vector of prices, X_t a vector of exogenous factors affecting prices, the A_i are matrices of coefficients, and e_t is a vector of error terms representing exogenous, serially independent, but unobservable, market shocks (with $\mathrm{cov}(e) = \Sigma$).

A large number of studies involve tests of the LOP or of perfect market integration that can be expressed as restrictions on the coefficients of the basic model. As we have discussed above, however, the model involves the simultaneous determination of prices and requires that careful attention be paid to model identification. This issue will be discussed in some detail in what follows. Many studies have not addressed the identification issue directly but have made implicit choices with implications that often are not fully considered. Some approaches do not depend on identifying assumptions but instead use the reduced form model in which $A_0 = I_n$. For example, Granger causality tests express the null hypothesis in terms of zero-restrictions on off-diagonal elements of the A_k. Price j fails to Granger-cause price i if the ij-th elements of all of the A_k $(k > 0)$ equal zero.

Cointegration techniques also make use of reduced form parameter restrictions. Cointegration tests address the long-run tendencies of a dynamic system and have been used to evaluate long-run equilibria. Intuitively, cointegration occurs when prices are nonstationary but have linear combinations (across space and/or time) among them that are stationary. There has been some debate concerning what kinds of cointegration relationships should be expected in spatial prices. It is often claimed that bivariate cointegration is a necessary condition in efficient and integrated markets. Others have argued that the stronger condition that price differences be stationary (that a one-to-one long-run relationship between a pair of prices be maintained) is also necessary. Furthermore, in a system of n prices, the number of cointegration relationships present has been taken to be an indication of the degree of integration in the market as a whole. The following section examines these methods in light of a simple point-location model of spatial price determination.

4.2.1. Dynamic regression models based on a point-location model

To make dynamic regression models of spatial prices economically interpretable, it is desirable to have an explicit economic model that yields the model. One economic model that meets these criteria is a point-location model with linear excess demand functions:

$$q_{it} = b_i(a_{it} - p_{it}). \tag{30}$$

The equilibrium conditions for the two-location model in which location 1 always exports to location 2 can be written in matrix form as the linear equations[10]

$$\begin{bmatrix} b_1 & b_2 \\ -1 & 1 \end{bmatrix} \begin{bmatrix} p_{1t} \\ p_{2t} \end{bmatrix} = \begin{bmatrix} b_1 a_{1t} + b_2 a_{2t} \\ r_t \end{bmatrix}. \tag{31}$$

Notice that, although there are three forcing variables (a_{1t}, a_{2t}, and r_t), two of them always appear together. Suppose the forcing variables can be written as a VAR:[11]

$$x_t = \sum_{k=1}^{m} B_k x_{t-k} + v_t, \tag{32}$$

where $x_{1t} = b_1 a_{1t} + b_2 a_{2t}$ and $x_{2t} = r_t$. Eliminating the forcing variables results in a VAR in prices:

$$\begin{aligned} \begin{bmatrix} b_1 & b_2 \\ -1 & 1 \end{bmatrix} p_t &= \sum_{k=1}^{m} \begin{bmatrix} B_{11k} & B_{12k} \\ B_{21k} & B_{22k} \end{bmatrix} \begin{bmatrix} b_1 & b_2 \\ -1 & 1 \end{bmatrix} p_{t-k} + v_t \\ &= \sum_{k=1}^{m} \begin{bmatrix} B_{11k} b_1 - B_{12k} & B_{11k} b_2 + B_{12k} \\ B_{21k} b_1 - B_{22k} & B_{21k} b_2 + B_{22k} \end{bmatrix} p_{t-k} + v_t. \end{aligned} \tag{33}$$

At issue is what restrictions, if any, spatial equilibrium imposes on the coefficients of this model. Four approaches to spatial price analysis using the basic dynamic regression model are discussed in this section: Granger causality tests of efficiency and market dominance, the market integration criteria of Ravallion and of Timmer, dynamic multiplier and impulse analysis, and cointegration. Table 1 contains a summary of a number of studies that use dynamic regression models to analyze spatial commodity prices.[12]

4.2.2. Granger causality and lead/lag relationships

Granger causality tests are typically conducted within the framework of a vector autoregression model where regional prices for one market are regressed upon lagged values

[10] The model formulated here is expressed in terms of price levels and assumes that transport costs are absolute (not dependent on the commodity price). Many analysts use log price specifications, which can be justified if transport rates are expressed in percentage terms. It may be that transport rates are a mixture of these (e.g., insurance may be a percentage of the value of the shipment and freight rates are per unit). In the mixed case, the model must be modified and interpretation of dynamic regression is even more problematic.

[11] Henceforth the deterministic variables are eliminated to avoid notational clutter; equivalently, the variables are expressed as deviations around a deterministic function.

[12] A large literature exists dealing with market integration in other goods, especially in financial markets. This review concentrates on goods that are expensive to transport relative to their value, as is true of most agricultural products.

of prices in another market. Significant coefficients imply that shocks to prices in one market evoke significant responses in another, with a lag. Granger (1969) formalized the notion of causality in terms of lead and lag relationships among dynamically interrelated variables. The use of the terminology "causality" often leads to some misunderstanding about the implications of the tests since the tests allow inferences only about lead/lag relationships and have little to say about actual causal elements leading to dynamic adjustments. The reduced form, in terms of the economic model's parameters, can be expressed as

$$p_t = \frac{1}{b_1+b_2}\sum_{k=1}^{m}\begin{bmatrix} 1 & -b_1 \\ 1 & b_1 \end{bmatrix}\begin{bmatrix} B_{11k} & B_{12k} \\ B_{21k} & B_{22k} \end{bmatrix}\begin{bmatrix} b_1 & b_2 \\ -1 & 1 \end{bmatrix} p_{t-k} + v_t = \frac{1}{b_1+b_2}$$
$$\times \sum_{k=1}^{m}\begin{bmatrix} B_{11k}b_1 - B_{12k} - B_{21k}b_1b_2 + B_{22k}b_2 & (B_{11k} - B_{22k} - B_{21k}b_2)b_2 + B_{12k} \\ (B_{11k} - B_{22k} + B_{21k}b_1)b_1 + B_{12k} & B_{11k}b_2 + B_{12k} + B_{21k}b_1b_2 + B_{22k}b_1 \end{bmatrix}$$
$$\times\, p_{t-k} + v_t. \tag{34}$$

The hypothesis that p_1 fails to Granger-cause p_2 is the hypothesis that the lower left-hand elements of the coefficient matrices are all zero:

$$(B_{11k} - B_{22k} + B_{21k}b_1)b_1 - B_{12k} = 0 \quad \text{for all } k. \tag{35}$$

This hypothesis would be accepted if B_{12k} and either b_1 or $B_{11k} - B_{22k} + B_{21k}b_1$ are small enough. Similarly the hypothesis that p_2 fails to Granger-cause p_1 is

$$(B_{11k} - B_{22k} - B_{21k}b_2)b_2 + B_{12k} = 0, \tag{36}$$

which would be accepted if B_{12k} and either b_2 or $B_{11k} - B_{22k} + B_{21k}b_1$ were both small enough.

Granger and Elliott (1967) evaluated spatial price relationships among eighteenth century prices at several English wheat markets. Their results revealed significant interactions and suggested that adjustments to price shocks at spatially distant locations were often of a dynamic nature. Gupta and Mueller (1982) used Granger causality to examine price adjustments among spatially separated hog markets in Germany. They interpret the finding of causality to be suggestive of inefficient markets since it implies the existence of a lead/lag relationship. Such a conclusion is questionable in light of the potential for dynamics in the price adjustment process owing to delivery lags and other impediments to interregional trade.[13] Indeed, Granger (1988) has shown that cointegration, which implies a long-run equilibrium relationship among a pair or set of economic

[13] In fact, Granger (1980, 1988) has argued that instantaneous causality is unlikely for most economic variables and that results consistent with such a finding usually reflect inappropriate temporal aggregation or omitted variables.

variables and thus has often been used to evaluate market integration, implies the existence of Granger causality in at least one direction.

Gupta and Mueller (1982) argue that the failure of one price to be predictive of another when the second is predictive of the first (unidirectional causality) is an indication that the second price is not incorporating the price information from the first region. Unidirectional causality is, therefore, taken to indicate that a market is informationally inefficient. An alternative explanation for unidirectional causality is suggested by Brorsen et al. (1985, p. 1): "Supply/demand fluctuations in a location with a large volume of commodity trading represent a larger shift in aggregate supply/demand, thus these locations are expected to have a larger influence on prices in other locations".

This can be demonstrated by considering when the simple point-location model would produce such a result. B_{12k} will be small if lagged transport rates have little impact on excess demand shocks. This is not unreasonable and implies that one is likely to find that p_1 fails to Granger-cause p_2 when p_2 Granger-causes p_1 in a situation in which b_2 is much larger than b_1 (i.e., when the amount demanded is far more sensitive to a given change in the absolute price level at location 2 than at location 1). This tends to happen when location 2 is a much larger market than is location 1. Thus, a sufficient condition for one-directional Granger-causality in prices is that a dominant/satellite market structure exists. Garbade and Silber (1979) and Koontz, Garcia and Hudson (1990) used this kind of test to detect such market relationships.

Alexander and Wyeth (1994) used Granger causality tests within the context of cointegration tests to evaluate spatial integration for Indonesian rice markets. Their results revealed patterns of causality, in terms of lead/lag relationships among several spatially distant markets. Alexander and Wyeth (1994) emphasize that Granger causality tests are necessarily implicitly nested within dynamic regression models and thus patterns of Granger causality should be considered to enrich the inferences offered in empirical studies. In a similar vein, Goodwin, Grennes and McCurdy (1999) used Granger causality within the context of multivariate cointegrated systems to evaluate spatial linkages among regional food markets in the post-reform Russian Federation. Their results reveal significant dynamics in the adjustment of prices to shocks in other regions.

Although Granger causality tests may provide some inferences regarding the existence of statistically significant lead/lag linkages among regional prices, a number of shortcomings limit their usefulness. First, Granger causality tests, taken by themselves, indicate only whether a relationship among contemporaneous and lagged prices is statistically different from zero. Without appealing to other tests or other means for inference, nothing is said about the actual nature of the relationship (i.e., about the values of the parameters being evaluated). A statistically significant relationship that is totally inconsistent with conventional notions of market integration could exist and be taken as support for spatial integration by Granger causality tests. Thus, it is imperative that results of Granger causality tests be supplemented by other inferential procedures to ensure that mistaken inferences are not drawn.

The limitations associated with standard regression and correlation coefficient approaches to testing market integration are also applicable to Granger causality tests. In particular, the independent variation of prices within a transactions cost band could lead to parameter estimates that have any value (including zero) but are entirely consistent with fully efficient markets. Granger causality tests are also sensitive to omitted variables biases. Finally, it should be noted that Granger's (1969) original notion of causality was based upon improvements in the forecasting performance of structural or nonstructural time-series models that resulted from including additional variables.[14] In standard tests, such forecasting is done within the same sample used to estimate the parameters of the forecasting model. A logical inconsistency is inherent in such an "in-sample" approach in that the parameter estimates underlying the forecasts are based upon information that is available only subsequent to the period being forecasted. As an alternative to this standard in-sample approach, Ashley, Granger and Schmalensee (1980) developed out-of-sample Granger causality tests which are based upon forecasts generated out-of-sample. These tests are closer to the spirit of causality originally discussed by Granger (1969) but have not, as yet, found their way into empirical analyses of causality among spatially separated prices.

The results of Granger causality tests should, therefore, be interpreted with caution. If one finds unidirectional causality in a market that should not exhibit dominant/satellite relationships, it would be an indication that the market should be analyzed carefully. At this stage, however, it would be premature to conclude that it indicates market inefficiency, as no convincing model of an inefficient market exhibiting this phenomenon has been developed.

4.2.3. Ravallion/Timmer market integration criteria

Ravallion (1986) and Timmer (1987) have proposed tests of market integration based upon dynamic regression models. In a general sense, these models can be interpreted as vector autoregressive models with tests of restrictions on the reduced-form parameters of the models. In this way, the dynamic regression models are alternative, dynamic versions of standard regression models and Granger causality tests. Ravallion's model is based upon regressions of the form

$$P_{it} = \sum_{s=1}^{n} a_{is} P_{it-s} + \sum_{s=0}^{n} b_{is} P_{1t-s} + X_{it} c_i + e_{it}, \tag{37}$$

where P_{it} is the price in regional market i in time t, P_{1t} is the price in a central market, and X_{it} represents a vector of characteristics influencing regional markets. Ravallion's test is cast in the framework of radial linkages among a number of hinterland

[14] Granger (1969) defines causality between two time series, X_t and Y_t, as follows: X_t causes Y_t if X_t contains information not available in Y_t that helps forecast Y_t.

markets and a central reference market important for price discovery. Ravallion defines several criteria for integration. Short-run market integration exists between the central market and the regional market if $b_{i0} = 1$ and if $a_{is} = b_{is} = 0$ (for all $s = 1, \ldots, n$), which implies that shocks in the regional market are immediately passed on to the i-th market price. Ravallion defines a weaker form of short-run integration to exist in cases where the lagged effects vanish on average, which requires only that $b_{i0} = 1$ and $\sum_{s=1}^{n} a_{is} + b_{is} = 0$. A long-run version of market integration exists when market prices are equalized over the long run, which requires that $\sum_{s=1}^{n} a_{is} + \sum_{s=0}^{n} b_{is} = 1$. It can be noted that short-run integration implies long-run integration but that the reverse is not true. Ravallion (1986) applies this test to first-differenced monthly price data to evaluate spatial linkages among Bangladesh rice markets. He finds that support for integration, even in the long run, is quite limited.[15]

Ravallion's three criteria for integration can be interpreted in terms of the structural econometric model. Recall that short-run integration implied that $b_{i0} = 1$ in (37). This is directly implied by the equilibrium condition. The added restriction that required that $a_{ij} = b_{ij} = 0$ (for all $j = 1, \ldots, n$) in Equation (37), can be expressed in terms of the structural point-location model as

$$B_{22k} - B_{21k} b_1 = -B_{22k} - B_{21k} b_2 = 0 \quad \text{for all } k. \tag{38}$$

It is difficult to justify such a restriction. It is only true if $B_{21} = B_{22} = 0$ for all k, implying that transport rates exhibit no persistence. It is not surprising that this condition is virtually always rejected (transport rates, like many prices, tend to exhibit serial correlation). As noted above, lagged price effects do not in themselves indicate market imperfections.

Ravallion's weak-form short-run restriction, suggesting that the lagged effects vanish on average, can be written in terms of the econometric model implied by Equation (33) as

$$\sum_k (B_{22k} - B_{21k} b_1 - B_{22k} - B_{21k} b_2) = -(b_1 + b_2) \sum_k B_{21k} = 0. \tag{39}$$

If b_1 and b_2 are positive (demand is not perfectly elastic), this restriction can be expressed as $\sum_k B_{21k} = 0$. The B_{21k} measure the effect on the transport rate of lagged excess demand shocks. This restriction can be interpreted to say that excess demand

[15] Faminow and Benson (1990) combine the agents-on-links framework with the existence of imperfect competition at the market centers and conclude that Ravallion-type tests should be reinterpreted. They argue that the short-run tests are symptomatic of a base point pricing system (collusion) in which one firm (location) sets a base price and other locations match that price net of transport costs. This conclusion rests on the assertion that competitive price adjustments must take time. Such adjustments could occur within a week or month, the intervals generally used in studies of spatial prices.

shocks have no long-run effect on the transport rate. To the extent that this is a reasonable assumption, the weak-form criterion can be derived in the context of this point-location economic model. It can be argued that an even stronger criterion may be justified if it is assumed that $B_{21k} = 0$ for all k, which is the same as saying that excess demand shocks do not Granger-cause the transport rate. If such an assumption is valid, then a revised strong-form short-run criterion requires only that $b_{i0} = 1$ and $a_{ij} + b_{ij} = 0$ for all j. It should be noted that the weak form criterion does not imply a weaker equilibrium condition but rather a weaker identification assumption concerning the driving forces.[16]

Ravallion also proposed a test for market isolation or segmentation. In isolated markets, prices are equal to the autarky prices (the a_i). As Harriss (1979) noted, the autarky prices may be correlated contemporaneously. They should, however, fail to Granger-cause one another. In the two-location model, isolated markets have the VAR structure

$$p_t = \sum_{k=1}^{m} \begin{bmatrix} R_{11k} & 0 \\ 0 & R_{22k} \end{bmatrix} p_{t-k} + v_t. \tag{40}$$

This leads to the testable restrictions that $R_{12k} = R_{21k} = 0$ for all k (i.e., that prices fail to Granger-cause one another).[17]

Timmer (1987) also used a dynamic regression model but adopted somewhat different assumptions. Timmer assumed that central market prices are predetermined relative to hinterland prices and that a first-order model is sufficient to capture the price dynamics. Timmer relates hinterland market prices to prices in the central reference market through the following equation:

$$P_{it} = c_0(P_{1t} - P_{1t-1}) + (c_0 + c_{1i})P_{1t-1} + c_{11}P_{it-1}, \tag{41}$$

where P_{it} is the price in hinterland market i and P_{1t} is the price in the central reference market. In the context of this model, Timmer defined an index of market connectiveness (IMC) by

$$IMC_i = \frac{c_{11}}{c_0 + c_{1i}}. \tag{42}$$

[16] Ravallion (1986) also suggested that deterministic variables such as constants and seasonal terms should be zero in an integrated market. It is difficult to see how this assertion can be justified. A constant term in the arbitrage equation of the dynamic regression model should be present any time transport is costly. Furthermore, seasonality in transport rates, which is often present, will result in non-zero seasonal coefficients. Regime shift (dummy) variables and time trends can similarly be interpreted in terms of changes in transport rates.

[17] Ravallion's (1986) criteria are not symmetric. His proposed market structure is one with a central market and hinterland markets. His market segmentation criterion requires that the central market price fails to Granger-cause the hinterland price. In a segmented market situation, however, Granger-causality should not be present in either direction.

Timmer argued that, in highly integrated markets, the lagged effects of regional market shocks should be small relative to current and lagged central reference market shocks and thus that the IMC should be close to zero.

Timmer's index of market connectiveness can also be interpreted in the context of a point-location model. Recall that Timmer argued that the IMC should be close to zero for highly integrated markets. A different interpretation of the index emerges from considering the measure in terms of the parameters of the economic model in the fully integrated case. In a two-location model,

$$IMC = \frac{B_{22} - B_{21}b_1}{1 - B_{22} - B_{21}b_1}. \tag{43}$$

If the identification restriction that $B_{21} = 0$ is imposed, the measure can be written as

$$IMC = \frac{B_{22}}{1 - B_{22}}. \tag{44}$$

Recall that B_{22} measures the autocorrelation coefficient on transport rates, which should lie on the $[0, 1]$ interval. This measure could therefore be interpreted as a measure of transport rate persistence; it is not clear how this relates to market integration.

Suppose, on the other hand, that the locations are actually isolated, so the reference price has no effect on the hinterland price, and

$$c_0 = c_{12} = 0. \tag{45}$$

In this case, Timmer's market integration index will be large (indeed, infinitely so), as it should be as an indicator of weakly integrated markets. This poses a dilemma. A large value of the IMC may indicate that the locations are not integrated or it may indicate that they are integrated and that transport rates exhibit a high degree of persistence. On the other hand, a low IMC suggests that the markets are not isolated but it is unclear how connected they are. Timmer's IMC, like Ravallion's strong form criterion, is useful only if one has independent confirmation that transport rates are white noise processes.

4.2.4. Impulse response analysis

Impulse responses represent the effects of exogenous shocks to variables in terms of a moving average representation of the VAR system. Impulse responses have been used in the framework of VAR systems comprised of a set of prices to examine dynamic issues related to spatial market integration. For a system of n regional prices, a set of impulse responses, reflecting the effects of exogenous shocks to prices in each of the n markets on prices, would be given by[18]

[18] Deterministic terms are again suppressed.

$$p_t = \sum_{k=0}^{\infty} M_k e_{t-k}, \tag{46}$$

which expresses the prices as functions of current and lagged shocks (impulses). An impulse response function (IRF) traces the impact over time of shock j on price i: the ij-th elements of the M_k expressed as a function of k. With n prices there are n^2 of these functions. Goodwin, Grennes and McCurdy (1999) evaluate spatial market linkages in post-reform Russia using impulse responses. They argue that such an approach provides richer inferences regarding the dynamics of price adjustments than standard regression analyses since the impulse responses evaluate the dynamic time-path of responses to market shocks. They also argue that impulse responses provide a dynamic alternative to standard "all-or-nothing" tests of market integration since they allow one to examine the extent of eventual price adjustment over time. Responses to price shocks in a regional market that are significantly different from zero but are not consistent with absolute price equalization may be taken as at least partial support for market integration. Williams and Bewley (1993) used impulse response analysis to examine spatial price relationships for Australian cattle markets.

A number of analysts have interpreted impulse response functions as dynamic disequilibrium adjustments. This interpretation can be justified only if the underlying shocks are serially uncorrelated. An alternative interpretation is that the impulse response functions reflect equilibrium adjustments to ongoing changes in economic fundamentals; this view is explicit in Equations (31)–(33). It is difficult to determine which of these alternatives is correct on the basis of price data alone due to identification problems.

In either case, to meaningfully interpret the IRFs, the shocks must be given an economic interpretation. A standard practice is to assume that the shocks are uncorrelated and that A_0 (in (29)) is triangular for some ordering of the variables, implying that prices form a causally recursive system. Such an approach assumes a set causal ordering of variables. A_0 can then be estimated as the Choleski decomposition of the reduced-form error covariance matrix. System recursivity, however, is a strong identifying assumption, implying a belief that shocks affecting some prices have no immediate impact on other prices. It is inherently untestable and, to be believable, must be justified on a priori grounds. A common approach in the literature is to examine several orderings in order to evaluate the sensitivity of the results to the ordering assumed for the system. Such an approach necessarily involves some degree of misspecification, however, and should not be assumed to provide an explicit test of the validity of assumed causal orderings. As Leamer (1985) points out, this is tantamount to the assumption that one is certain that instantaneous causality only flows in one direction but uncertain of the direction of that flow [see also Cooley and LeRoy (1985)].

There is another reason to interpret results based on a recursivity assumption with caution. In the context of a dynamic spatial price regression, recursivity amounts to imposing a particular kind of disequilibrium on the model. Shocks that originate in one location, it is assumed, have no immediate effect on prices at some of the other locations, which can be interpreted as an informational inefficiency. If the intent is to study the efficiency of the market, it is not a good practice to impose inefficiency on the market a priori.

To our knowledge, no studies have been published that make use of non-recursive identifying assumptions in the context of a model of spatial prices. Indeed, we know of only one such application to agricultural markets: Myers, Piggott and Tomek (1990). A useful discussion is contained in Tomek and Myers (1993).

4.2.5. Cointegration analysis

In recent years, it has been recognized that many economic variables behave as if they are nonstationary, and unit-root nonstationarity seems to be particularly common.[19] This is particularly true of nominal prices, which often trend and wander extensively over time. The presence of nonstationarity in the price series commonly used to test spatial market integration invalidates conventional approaches to inference. In particular, parameter estimates of common regression tests for cointegrated prices, based on a regression model such as Equation (26), though consistent, will have inconsistent standard error estimates.[20] Recognition of this issue and recent advances in econometric techniques appropriate to nonstationary variables has stimulated an extensive literature applying unit-root and cointegration tests to evaluations of spatial integration. Nearly half of the papers in Table 1 apply cointegration methods to spatial prices.

Cointegration tests typically evaluate the equilibrium parity condition implied by spatial arbitrage:

$$p_{1t} - \alpha - \beta p_{2t} = e_t, \tag{47}$$

where p_1 and p_2 represent prices in two spatially separated markets. As noted, if p_1 and p_2 are nonstationary, regression estimates of the standard errors on the estimates of α and β will not be consistent. Cointegration tests consider the time-series properties of the residual term e_t. If the residual is stationary, the implication is that, although p_1 and p_2 wander extensively on their own, they are linked in a long-run, stable equilibrium.

Although early analyses of cointegration were primarily of a bivariate nature, multivariate versions of cointegration relationships have also been considered. Consistency with the notion of a single price implies that a group of n prices should have $n - 1$ cointegration relationships (cointegration vectors).[21] This implies that any one of the prices can be solved for in terms of any other single price or, equivalently, that any single price

[19] A time-series variable is unit-root nonstationary if the characteristic equation associated with its autocorrelation function has a unit eigenvalue.

[20] See Engle and Granger (1987) for a detailed discussion of the properties of ordinary least squares estimates when variables are nonstationary, as well as a series of bivariate cointegration tests.

[21] Cointegration relationships are often equivalently expressed in terms of the number of common stochastic trends that exist among the group of variables. For n prices, $n - 1$ cointegration vectors implies a single common trend.

is representative of the group. Of course, the values of the cointegration vectors are relevant to the nature of the relationship among prices. Multivariate cointegration tests are usually conducted in the context of the reduced form of a vector autoregressive (VAR) model (Equation (29) with $A_0 = I_n$):

$$p_t = A_1 p_{t-1} + \cdots + A_k p_{t-k} + v_t. \tag{48}$$

The appropriate approach to estimating this relationship depends upon whether the individual prices are stationary and, in the case of nonstationarity, whether cointegration relationships exist. If the prices are stationary, standard OLS estimation procedures can be applied and standard inferences regarding causality and impulse responses can be obtained. However, if they are nonstationary, standard estimation procedures may be inappropriate. Furthermore, if the data are cointegrated, first-differencing transformations may induce an important model misspecification and thus are not appropriate.

A frequently applied test for cointegration is the maximum likelihood approach of Johansen (1988) and Johansen and Juselius (1990). The VAR Equation (33) can be written in error-correction (first-differenced) terms as

$$\Delta p_t = G_1 \Delta p_{t-1} + \cdots + G_{k-1} \Delta p_{t-m+1} - B p_{t-m} + v_t. \tag{49}$$

If prices are nonstationary but are cointegrated, the matrix given by

$$B = I_n - A_1 - \cdots - A_m \tag{50}$$

will be of some rank r such that $r > 0$ and $r < n$. Johansen and Juselius's tests evaluate the rank of B. If the rank of B is r, then there are r unique cointegrating vectors among the n prices.

Cointegration-based tests are tests of long-run tendencies rather than of period-by-period equilibria. These tests are generally justified by the assertion that arbitrage opportunities prevent spatial prices from drifting too far apart. Within the context of a linear dynamic regression model, the only way that nonstationary prices can be assured of not drifting too far apart is to have stationary price spreads.

At first glance the notion that spatial prices cannot drift apart in an efficient market has some intuitive appeal. It should be noted, however, that at a minimum this assertion makes the implicit assumption that transport rates are stationary or, in the case of tests using logarithmic transformations, are proportional to prices. Clearly, if transport rates are non-stationary then prices that are observed to drift apart may not represent arbitrage opportunities at all. In the simple point-location model with stable trading patterns the price spread is equal to the transport rate and thus should reflect its stationarity properties. Thus cointegration is not a necessary condition for market efficiency and integration. Some evidence for this is found in Goodwin (1992a) who showed that wheat prices in three locations (U.S. Gulf, Rotterdam, and Japan) exhibited a cointegration relationship which was potentially sensitive to ocean freight rates. Examination of the freight rates suggested that the Gulf–Japan rate was nonstationary.

One of the first applications of cointegration analysis to an evaluation of spatial market linkages is Ardeni's (1989) study of the law of one price for internationally traded agricultural commodities. Ardeni's study was motivated by neglect of the issue of nonstationarity in the literature as well as by the differencing transformations often used to address serial correlation in empirical work [e.g., Richardson (1978)].[22] Ardeni argued that individual prices in spatially integrated markets may wander extensively on their own and may diverge from one another for brief periods of time but should not wander too far apart in the long run. Thus, he argued that prices should be cointegrated. His analysis found relatively limited evidence of cointegration in international commodity markets and thus he concluded that the law of one price was not supported in the international markets for basic commodities that he considered. Baffes (1991) pointed out that cointegration alone is not sufficient to conclude that the LOP holds. He suggested that the linear relationship between prices should have a slope of one, or, equivalently, that price spreads are stationary.

Goodwin and Schroeder (1991b) used a variety of cointegration tests to evaluate spatial linkages among regional U.S. cattle markets. Their results revealed strong linkages among weekly prices. Cointegrating parameter estimates were also consistent with a reasonably strong tendency toward price equalization. Using a similar approach, Alderman (1993) utilized cointegration tests and versions of Ravallion's (1986) regression tests to evaluate integration in Ghana grain markets.

Cointegration tests have the advantage of allowing consistent inferences to be drawn in situations where the individual price series are nonstationary. However, like other regression-based tests, cointegration tests are vulnerable to the problems associated with spurious regression results and transactions costs. An extensive discussion of the shortcomings of cointegration tests of spatial market integration is offered by McNew and Fackler (1997). A fundamental shortcoming associated with the cointegration approach lies in the possibility that transactions costs may be nonstationary. In general, deviations from a parity condition such as that implied in Equation (47) are generally assumed to reflect unobserved elements of transactions costs. If such elements are indeed nonstationary, a set of prices may not be cointegrated in spite of the fact that they are clearly linked in a long-run equilibrium and thus are consistent with conventional views of market integration. A limited number of studies have attempted to adjust price differentials for transactions costs.

It may also be the case that equilibrium prices are cointegrated in spite of the fact that markets are not directly linked with one another. Such a situation would most likely be observed in cases where the transactions cost band is relatively large and the price differential is stationary but always within the transactions cost band. In light of these

[22] As Ardeni (1989) notes, differencing transformations may be inappropriate for cointegrated variables in that they may introduce an important misspecification in the empirical model.

limitations, one would intuitively expect that cointegration tests are most appropriate in applications where the transactions costs are small relative to the prices being evaluated.[23]

Barrett (1996) notes that cointegration could be consistent with a negative relationship between prices when market integration suggests a positive correlation. This is indeed similar to the general problem (noted above in the context of Granger causality tests) of examining the significance of the relationship without considering the nature (direction) of the relationship. Thus, cointegration, taken without additional considerations (such as an evaluation of impulse responses or cointegrating parameters), provides limited and potentially misleading information about spatial market linkages.

If the transport rate is stationary, the simple point-location model can be used to derive testable restrictions on the price VAR. For example, one can show that, if $n-1$ cointegrating relationships exist in an n-location model, an efficient and well-integrated market will exhibit stationary price spreads. Stationarity of price spreads can, therefore, be used to suggest that markets are efficient and integrated in the long run.

The relationship between cointegration and efficiency, however, is complex, even if the transport rate is stationary. In the alternative models considered (the switching regime, the point-location with upward-sloping transport supply, and the agents-on-links models), price spreads depend on all of the model's shocks. For example, with upward-sloping transport supply, the price spreads are given by Equation (15) and are a function of both transport rate and reservation prices. Transport rate stationarity, therefore, is not sufficient to ensure price spread stationarity in an efficient market. One must also have stationarity of excess demand shock differences as well. Although this is possible, spatial arbitrage cannot be the mechanism that ensures it. In the switching regime model, it is possible to have an efficient market with changing trading patterns and fail to observe cointegration or stationary price spreads [McNew and Fackler (1997)].

A tentative conclusion that emerges from these remarks is that price spread stationarity is consistent with a market in which locations are, in the long run, both efficient and fully integrated. This means that, in some sense, the market equilibrates in the long run (arbitrage opportunities are exploited) and that shocks originating in one location are eventually transmitted fully to the other location. On the other hand, a conclusion that the price spreads are not stationary is more difficult to interpret. It may imply that the markets are in a long-run disequilibrium situation. More likely, however, it may imply that integration is less than complete, either because the markets become isolated or because marginal adjustments occur. In this case, however, conclusions about the extent of integration are difficult to justify using linear dynamic regression, either because a switching regime regression is more appropriate or because the structural model is not identified using only price data.

Before leaving the subject of long-run equilibria, it is useful to remark on alternative views of the meaning of this concept. There are two ways of evaluating long-run

[23] For example, cointegration tests of asset prices and rates of return may be more appropriate in light of the very small transactions costs associated with trades in organized asset markets.

impacts in dynamic systems. The first uses what have been termed the long-run multipliers. These measure the eventual impact on an endogenous variable of a permanent incremental change in the value of an observable exogenous variable:

$$\lim_{h\to\infty}\sum_{i=0}^{h}\frac{\partial\,\mathrm{E}_t[p_{t+i}]}{\partial x_t}. \tag{51}$$

The other long-run concept measures the eventual impact on an endogenous variable of a one-time incremental change in the value of one of the unobserved system shocks:

$$\lim_{h\to\infty}\frac{\partial\,\mathrm{E}_t[p_{t+h}]}{\partial e_t} \tag{52}$$

(i.e., the time limits of the impulse response functions).

A number of analysts, including Ravallion (1986), use the former concept, implicitly treating a central market price as exogenous. Notice that a hinterland price can be written as

$$p_{2t}=\frac{c_0-\sum_{k=1}^{m}c_{1k}\,\mathrm{L}^k}{1-\sum_{k=1}^{m}c_{2k}\,\mathrm{L}^k}\,p_{1t}+v_t=S(\mathrm{L})p_{1t}+v_t. \tag{53}$$

If p_1 were exogenous the long-run impact multiplier would be equal to $S(1)$. Setting this equal to 1 yields Ravallion's long-run integration criterion. In an integrated market, however, the central market price cannot be assumed to be exogenous, because this would be tantamount to assuming that shocks originating in the hinterland never affect the central market price.

Viewed from the perspective of impulse analysis, a long-run version of the strong form of the LOP requires that there be a mechanism through which some linear combination of shocks affects all prices equally in the long run. This means that there exists a vector θ such that $M_\infty\theta$ is the unit vector, where M_∞ is the long-run impulse response matrix. This condition is always true if prices are nonstationary and are not cointegrated. If prices are cointegrated, however, the condition is equivalent to $A(1)$ being orthogonal to the unit vector, which is easily tested. Furthermore, in a market in which there is a single source of non-stationarity, this is equivalent to the stationarity of price spreads.

In short, cointegration tests of spatial integration are heavily dependent upon assumptions which may, in many cases, be quite strong. These assumptions principally pertain to transactions costs, which are often assumed to be stationary or capable of being represented in an ad hoc simplistic manner. In this way, cointegration tests share a limitation common to most other empirical tests of spatial market integration.[24]

[24] Indeed, the neglect of transactions costs is a problem endemic to empirical economic analyses. Transactions costs are present in almost any exchange and may distort endogenous responses enough to significantly bias regression parameter estimates.

4.2.6. *Empirical determinants of market integration*

The overwhelming majority of analyses of market integration address only the question of whether, using whatever metric is are deemed appropriate to the analysis, markets are integrated. Most often, such questions are posed in a discrete yes/no framework, although some papers discuss the issue in terms of a degree or extent of integration. A natural (but often neglected) follow-up question involves a consideration of the factors that affect the extent or degree of integration. Only a small number of studies have evaluated determinants of spatial market integration. Goodwin and Schroeder (1991b) followed up their cointegration analysis of spatial linkages in regional livestock markets with an investigation of the factors that tended to influence the extent of cointegration (integration) among a pair of markets. Their results revealed that, as would be expected, distance between markets has a significant, negative influence on the degree to which a pair of market prices tended to be cointegrated. Likewise, they found that increasing concentration of the meat packing industry over time corresponded to increased cointegration among regional prices. This result is particularly important in that increased concentration of an industry is often suspected to lead to the increased exercise of market power through spatial price discrimination, which could be characterized by diminished market integration and thus a tendency for less integration.[25] However, as has been noted by Faminow and Benson (1990), market integration could be due to noncompetitive basing-point pricing practices of large buyers or sellers.

Goletti and Christina-Tsigas (1995) discuss a general framework for evaluating determinants of the degree of market integration. They suggest that such factors as marketing infrastructure (transportation, communication, and credit), price policies, infrastructure (roads, phone system, etc.), and labor issues such as strikes may be relevant to observed patterns of integration. Goletti, Ahmed and Farid (1995) identified several structural factors affecting the integration of rice markets in Bangladesh. They found that distance between markets, telephone density, and the presence of labor strikes had negative impacts on various measures of integration. In contrast, road density and the degree of inequality in production levels (indicating more regional trade) positively affected the degree of market integration. Goletti (1993) found that severe supply shocks, such as major floods, had a negative impact on market integration.

In general, the fundamental question of market integration goes beyond simple considerations of whether prices are integrated. Inferences regarding factors affecting revealed patterns of integration are richer and perhaps more informative. As a general rule, however, such inferences are lacking in the empirical literature.

[25] Increased concentration of the livestock packing industry has brought about complaints that prices in regional livestock markets have been driven down and that spatial differences have increased as a result of discriminatory pricing practices.

4.3. Switching regime models

One difficulty with dynamic regression models is the lack of a clearly articulated alternative to the null hypothesis that markets are perfectly integrated. This is problematic when a market is imperfectly integrated because the network of trading linkages changes over time. Timmer (1987), for example, suggested that seasonal changes in the import/export status of regions would lead to difficulties in identifying the degree of market integration. This theme was echoed recently by Baulch.

A potentially more appropriate modeling approach has been developed using the switching regime regression model. Spiller and Wood (1988) suggested this approach in a model of northeast U.S. gasoline markets. They suggested that three regimes are possible in a two-location market, which, expressed in the notation of this chapter, are:

(1) location 1 ships to location 2 if $a_{2t} - a_{1t} > r_{12t}$;
(2) location 2 ships to location 1 if $a_{2t} - a_{1t} < -r_{21t}$;
(3) no trade occurs if $-r_{21t} < a_{2t} - a_{1t} < r_{12t}$,

where r_{ijt} is the transport rate for shipping the commodity from location i to j at time t (it is possible that $r_{12t} \neq r_{21t}$).

Switching regime models provide estimates of the probabilities of being in each regime, both ex ante and ex post (conditional on the size of the observed price spread).[26] To make the model tractable, they impose quite strong assumptions on the dynamic processes generating the excess demand shocks and transport rates. In particular they assume that $a_{2t} - a_{1t}$, r_{12t} and r_{21t} are mutually and serially independent. Currie (1995) recently estimated a similar model that relaxes some of these assumptions.

In the Spiller and Wood (1988) approach, a test for market integration shifts from a test of regression coefficients within a regime to a test of the size of the regime probabilities. The hypothesis of a well-integrated market with a stable trade pattern (say with trade from location 1 to 2) is equivalent to the hypothesis that the associated regime probability equals 1 and that the others' regime probabilities are each zero.

Sexton, Kling and Carman (1991) examine the issue of market efficiency rather than integration. They study a market (U.S. celery) that can safely be assumed to be linked by unidirectional trade (say from location 1 to 2) and develop a switching regime model in which arbitrage conditions may be violated. Their model is similar to that of Spiller and Wood's in that they use a switching regime regression approach, but the three regimes are defined in the following way:

(1) $p_{2i} - p_{1t} < r_{12t}$,
(2) $p_{2t} - p_{1t} > r_{12t}$,
(3) $p_{2t} - p_{1t} = r_{12t}$.

Only in regime 3 are the markets efficient, and hence efficiency is equivalent to the hypothesis that the probability of regime 3 is equal to one and the other regime probabilities equal zero. Baulch (1994, 1997) proposed an alternative switching regime model

[26] These models typically endogenize the probability of the market being in each of the possible regimes.

in which the regimes correspond to prices within the arbitrage band (no trade), prices at the arbitrage band (efficient trade), and price outside the arbitrage band (inefficient trade).

In all of these approaches the probability distribution associated with the price spread is a mixture of three distributions:

$$f(s_t|\theta) = \lambda_1 f_1(s_t|\theta_1) + \lambda_2 f_2(s_t|\theta_2) + (1 - \lambda_1 - \lambda_2) f_3(s_t|\theta_3), \tag{54}$$

where $s_t = p_{2t} - p_{1t}$, and θ_j are parameters defining the regime probability distributions, and λ_1 and λ_2 are the ex ante probabilities that the market will be in regimes 1 and 2, respectively.[27] In Spiller and Wood, $\lambda_1 + \lambda_2$ can be thought of as a measure of the degree of integration of the market. In Baulch it is a measure of the efficiency of the market (which he calls the integration of the market). In Sexton, Kling and Carman it is a measure of the inefficiency of the market.

Switching regime models are problematic, however, in that a far simpler interpretation for the "probabilities" exists when it is recognized that use of a mixture distribution is a standard way to flexibly model a probability distribution. These models can be viewed as nothing more than flexible models of the price spread distribution. The believability of the regime interpretation rests very strongly on the believability of the distributional assumptions. For example, both Spiller and Wood (1998) and Sexton, Kling and Carman (1991) assume that f_3 is normally distributed. Furthermore, in both papers the other two regimes are one-sided (support on only one side of the mean of f_3). The empirical results could therefore be interpreted as measuring the degree to which the price spread distribution deviates from normality above and below its mean. Inasmuch as economic theory generally has little to say about the normality of such a distribution, this seems to be a rather fragile approach with which to analyze spatial price patterns.

An additional problem with the switching regime models concerns the assumption of no serial correlation in the forcing variables (shocks to excess demand and transport rates). These models also use the size of price spreads as an indicator of connectedness. It is possible, however, for locations to be connected by having common trading partners. Small price spreads between integrated locations can arise in this situation.

Recently, a different variation on the switching regime model has been applied to spatial price models. Obstfeld and Taylor (1997) use a Threshold Autoregressive (TAR) model in which a fixed but unknown transport cost is assumed to act as a threshold. When the price spread exceeds the threshold, it exhibits reversion towards the threshold. When the spread is within the transaction cost band, however, it is assumed to behave in a serially independent fashion. The model was applied to Indian wheat prices by Prakash (1996).

[27] A distinction between the approaches is that Spiller and Wood (1988) treat the λ_i as endogenous (functions of the ω_j), whereas Sexton, Kling and Carman (1991) treat them parametrically.

The TAR model provides both a probability of being outside the band (a measure of the degree to which the market violates the spatial arbitrage condition) as well as a measure of the speed with which it eliminates these violations (a kind of market efficiency measure). The model, however, is very highly parameterized and requires modification to capture a number of the regularities exhibited by commodity markets. In addition, these models are typically specified by assuming that transactions costs impose a fixed band on absolute or proportional price differences. This limitation occurs because of the general inability to actually measure transactions costs. In a recent exception, Goodwin and Grennes (1998) estimate a threshold autoregression model that has a variable threshold which is defined using actual transportation cost data. Their results confirm that support for integration is stronger when threshold effects are recognized.

4.4. Rational expectations models

Dynamic models of spatial market integration recognize the potential for significant lags in price relationships brought about by delivery lags and adjustment costs. These dynamic models have, for the most part, neglected to consider the role of expectations. Delivery lags necessarily raise the issue of price expectations since agents must formulate expectations about prices at the time of delivery. Delivery lags raise the issue of uncertainty and information-gathering costs, which may be a significant determinant of transactions costs. The presence of delivery lags and adjustment costs may also raise the possibility of noncontemporaneous price linkages. For example, consider a case of Florida celery growers selling in the eastern U.S. with a delivery lag of one week and in the western U.S. with a delivery lag of two weeks. Prices in eastern and western celery markets may be integrated through their common supply source; however, price shocks may take an additional period to be realized in western markets. Thus, linkages are not contemporaneous but may instead involve lags.

A simple model of regional arbitrage can be used to illustrate the potentially important role of price expectations and noncontemporaneous price linkages. The simple arbitrage condition discussed above presumed that markets are integrated by the profit-seeking actions of commodity traders and arbitrageurs. As has been emphasized, the spatial arbitrage problem is inherently dynamic because of delivery lags, adjustment costs, and other impediments to instantaneous commodity arbitrage and trade. Consider an arbitrageur at location 1 in possession of a single commodity. The agent has opportunities to sell, perhaps with some lag in delivery, in another location. We will assume that the agent has no storage opportunities.[28] The agent will act to maximize expected profits, where profits are given by

$$\pi(q_{1t}, q_{2t}) = p_{1t}q_{1t} + \left(\delta^j \, \mathrm{E}_t[p_{2t+j}] - r_t\right)q_{2t} - C(q_{1t} + q_{2t}), \tag{55}$$

[28] Storage can be added to the model with no loss of generality. With storage, arbitrageurs may choose to hold a commodity in storage at some positive costs rather than shipping it to a consuming market. In such a case, additional arbitrage conditions exist among expected prices, storage costs, and transportation costs.

where q_i is the quantity sold in market i ($i = 1, 2$), p_{it+j} is the price received upon delivery in market i, $C(\cdot)$ is a commodity arbitrage cost function representing the costs of acquiring and marketing the commodity, δ is a constant, real discount factor, and r_t is the per-unit transactions costs involved in marketing the commodity in location 2. Delivery lags are reflected by the fact that payment is received upon delivery after j periods.

First-order conditions for profit maximization for all $s > t$ are given by

$$p_{1t} = \delta^j \mathrm{E}_t[p_{2t+j}] - r_t = C'(q_{1t} + q_{2t}). \tag{56}$$

In making the transition to an empirical framework, one must consider the appropriate representation of price expectations, noncontemporaneous price linkages, and dynamic correlation structures that may result from forecasts that are made over many periods. Representation of price expectations may not be straightforward. Goodwin (1988) used observed futures and forward market price quotes as expected prices and found reasonably strong support for the law of one price. Goodwin, Grennes and Wohlgenant (1990a) utilized generalized method of moments estimators to explicitly model price expectations. In that their application considered markets that traded almost continuously, the concerns relating to price differences within transactions costs bands for markets in autarky are mitigated. They also used actual transportation costs to model transactions costs. Their results suggested that adherence to the arbitrage conditions underlying conventional versions of market integration is much more likely when ex-ante price expectations are explicitly considered than when ex-post price realizations are used in empirical tests.

As noted above, attention to delivery lags raises the possibility that price linkages will be of a noncontemporaneous nature. Goodwin, Grennes and Wohlgenant (1990b) utilized model specification tests to evaluate whether noncontemporaneous price linkages received stronger support than did conventional specifications assuming contemporaneous price relationships. For a variety of internationally traded grains and oilseeds, their results suggested that a two-month delivery lag was supported by the data. In a similar analysis, Sexton, Kling and Carman (1991) used specification tests in an evaluation of celery market integration using weekly prices to determine whether noncontemporaneous price linkages were supported over the more conventional contemporaneous relationships. Specification testing results implied that price linkages were contemporaneous for markets relatively close to one another but were more likely to involve lags for distant markets.

Finally, it can be noted that rational expectation models with delivery lags can lead to conventional vector autoregressive models in which lagged prices are used as instruments to identify price expectations, as in Goodwin, Grennes and Wohlgenant (1990a, 1990b). Consider a contemporaneous relationship for expected prices of the form which would result from an evaluation of two import markets, linked through a common export market with identical delivery lags:

$$\mathrm{E}[p_{1t+j}] - \mathrm{E}[p_{2t+j}] = \alpha_t, \tag{57}$$

where α_t represents the expected differential in transport rates. The relationship is contemporaneous by virtue of the identical j-step-ahead delivery lags. Instrumental variables estimation of these relationships typically involves representing the expectations by using projections from a first-stage regression against instrumental variables. When lagged prices are used in the first stage, this relationship can be rewritten as

$$\sum_{k=1}^{m} A_{1k} P_{1t-k} - \sum_{k=1}^{m} A_{2k} P_{2t-k} = \alpha_t. \tag{58}$$

5. Conclusions

The various empirical tests that we have reviewed each have their own limitations and none has emerged as being preferable in all cases or circumstances. As is true with most (if not all) empirical tests of economic phenomena, the potential exists for misleading test results and invalid conclusions. This is primarily due to the fact that empirical tests are almost always conditional on a number of augmenting hypotheses or simplifying assumptions which may or may not be explicitly stated.

Probably the most serious factor influencing the validity of empirical tests of integration involves transactions costs. Most tests of spatial integration do not explicitly consider transactions costs. This omission reflects the fact that direct observation of transactions costs is usually impossible; data on transportation charges are generally unavailable. Even in cases where freight charges can be directly observed or when reasonable proxy measures of transportation charges exist, transactions costs may involve many intangible elements that elude direct observation. Such intangibles include risk premia, information-gathering costs, negotiation costs, and the costs associated with maintaining a presence in a regional market. Many empirical tests simply abstract from considering the effects of transactions costs on spatial market linkages and proceed to test market conditions that would be expected if transactions costs were zero. Many others invoke simplifying assumptions about transactions costs. Common assumptions include representing transactions costs as a constant or a constant proportion of product prices or that transactions costs are serially uncorrelated. As we have established in preceding discussions, neglect of transactions costs can produce biases and misleading inferences in empirical tests.

Furthermore, prices in efficient and integrated spatial markets are endogenously and simultaneously determined. Although this should lead to testable restrictions on the behavior of prices, attempting to derive such restrictions from fully specified models of price determination demonstrates that this is not as simple as it might seem. Only one simple, highly stylized model, the point-location model, is capable of generating any of the tests of efficiency and integration that have been proposed in the literature. The simple point-location model leads to tests similar to those proposed by Ravallion and provides some justification for cointegration-based tests. It also can be used to demonstrate weaknesses in Timmer's perfect market integration criteria, impulse analysis based on recursive identifications, and Granger causality tests of market efficiency.

Although the point-location model is useful in generating a base-case model, it is difficult to see how it can justify the commonly used dynamic regression framework when the market fails to be well integrated and efficient. Some markets do not transmit local shocks on a one-to-one basis. For example, markets in which transport links break down in some periods or marginal adjustments occur in the transport linkages may fail to transmit local shocks to other markets. In such cases, it is not clear that a linear dynamic regression specification is appropriate. Thus, the dynamic regression model nests the null hypothesis but not reasonable alternatives. This makes it difficult to interpret test rejections, even when the tests are well founded under the null hypothesis of well-integrated and efficient markets.

Fortunately, these conclusions provide a basis for further investigation. The approach taken with the simple point-location model could also be applied to the other models of price determination. This would help to identify what kinds of price behavior should be expected given a richer set of assumptions about the price determination process.

Due to the interpretive difficulties in studies based on price data alone, a natural proposal is to use more complete market data to address spatial market issues. Barrett (1996) has argued that transport rate and trade flow data may be needed before some controversies are resolved. The discussion contained herein supports this view.

It is clearly essential that the limitations associated with unobserved transactions costs be recognized when empirical tests of integration are considered. To put such limitations in proper perspective, however, the wider role of transactions costs in empirical evaluations of economic phenomena should also be considered. Transactions costs are not just relevant to considerations of regional trade and arbitrage: they are present in any and every exchange. Likewise, despite their universal presence in every aspect of the market, transactions costs are usually ignored in empirical work. Regression analysis is typically used to estimate parameters (usually based upon derivatives) such as price transmission elasticities that describe and characterize the economic system of interest. As we have pointed out, transactions costs may result in discontinuities that complicate such inferences. In this light, almost all inferences have the potential to be complicated by unmeasured or unmeasurable transactions costs.

One may be quick to assume that transactions costs are less relevant in some exchanges than in others. In particular, it is clearly the case that the transactions costs inherent in interregional trade activities are far more significant than those associated with the purchases of a representative consumer. While this is certainly true, the important point is not the absolute magnitude of transactions costs but rather their significance relative to changes in other variables in the model. For example, in a model of consumer demand, transactions costs are small but potentially significant relative to the variability of demand function, and therefore may inhibit accurate estimation of demand parameters.

The important point is that empirical tests, by their very nature, are sensitive to factors such as transactions costs and other unobserved variables that may influence the responses of agents and thus may bias empirical estimates. This point is not meant to condemn or call into question the utility of empirical analyses. Rather, the implication is that the weaknesses and limitations associated with empirical assessments of economic conditions should always be recognized and kept in mind when making use of empirical estimates.

A specific problem with interpreting rejections of so-called market integration tests is that the null hypothesis is that the markets are both efficient and perfectly integrated. Without explicit information about transactions costs, rejections of the tests could be caused by either inefficiencies or lack of perfect integration (including, in the extreme case, market isolation). Rejections of the tests are inherently incapable of determining which. Furthermore, if test rejections are caused by lack of perfect integration, the regression model is misspecified. It is not clear how lack of integration would affect parameter estimates in a dynamic regression model and therefore whether any conclusions can be drawn about why the market fails to be integrated. One focus of future research should be the examination of the behavior of markets subject to specific kinds of market imperfections.

Preceding discussions pointed out that, because of these types of limitations, empirical tests supporting integration could be consistent with a complete lack of integration, and tests rejecting integration could occur in markets that are completely linked. These indeterminate results follow from a number of weaknesses inherent in the empirical tests, including a lack of information about transactions costs, model misspecifications, and weaknesses in the inferential procedures.

What, then, is to be learned from empirical tests? The essential ingredient necessary to properly interpret the results of empirical evaluations of market conditions is knowledge of the institutions and conditions pertinent to the markets in question. For example, knowledge that a continuous flow of goods existed between two markets greatly enhances the interpretation of tests of integration based upon prices alone. Likewise, one is often sure of a direction of commodity flow (i.e., from exporting to importing regions). Such knowledge is useful in interpreting the results of tests necessarily dependent upon strong simplifying assumptions. Recognition of patterns of seasonality or movements in aggregate prices may also enhance the interpretation of empirical tests of market integration.

Empirical tests of integration that are consistent with opposing views of market linkages may nevertheless be useful in terms of allowing one to rule out other conditions that do not support integration of markets. For example, tests which indicate a close correspondence of price changes in regional markets may be sensitive to spurious relationships inherent in cases where aggregate influences are affecting prices in all markets. However, such tests do allow one to rule out market conditions which would imply a divergence of prices over a long run. In this manner, empirical tests should be considered as diagnostic instruments in the empirical tool-kit used to assess market conditions. Diagnostic tests may not allow one to reach a definite conclusion regarding one aspect of market relationships, but may allow other conditions to be ruled out.[29] In this way, the tests may provide useful inferences in spite of their significant limitations.

Having noted such points, the key question remains: What can be learned about spatial market behavior from empirical tests based upon prices alone? These tests clearly provide information about spatial relationships among prices. However, the tests should be interpreted within the context of institutional and factual characteristics of the markets in question as well as the shortcomings associated with each test. The significant limitations associated with individual tests suggest that inferences should not be based upon a single test but rather, when possible, on a variety of inferential techniques.

An approach to evaluating spatial market integration on the basis of price data alone might include an examination of correlation coefficients and simple bivariate regression models as initial descriptive devices. Of course, the factors likely to cause misleading spurious correlation should also be given careful consideration. One might then examine the time series properties of the price data, including an evaluation of the stationarity of the price data. Inferential techniques such as Granger causality, dynamic multipliers, cointegration tests, and impulse responses might then be considered to further describe the nature of price relationships. As we have noted above, techniques such as Granger causality and cointegration tests might be of limited usefulness in terms of actually testing spatial market integration. Such tests may, however, be essential for suggesting the appropriate specification for use in further evaluation of price linkages. For example, Granger causality results may be useful in suggesting identifying restrictions for use in generating impulse responses. Likewise, cointegration test results are essential for determining the appropriate specification of vector autoregressive models.

In general, then, it is incumbent upon the analyst to be aware of the significant limitations associated with empirical tests of market integration and to temper inferences accordingly. A universal truth essential to interpreting empirical research is that knowledge of the institutions and facts regarding market conditions is essential. Empirical results must be interpreted within the institutional context and framework underlying the economic system being considered. Misleading inferences are always a hazard, and careful attention to such institutional details will minimize the potential for making them.

References

Adamowicz, W.L., S.O. Baah and M.H. Hawkins (1984), "Pricing efficiency in hog markets", Canadian Journal of Agricultural Economics 32:452–477.

Adler, M., and B. Lehmann (1983), "Deviations from purchasing power parity in the long run", Journal of Finance 38:1471–1487.

Alderman, H. (1993), "Intercommodity price transmittal: Analysis of food markets in Ghana", Oxford Bulletin of Economics and Statistics 55:43–64.

[29] The analog to diagnostic medical tests is clear. Medical diagnoses often proceed by ruling out certain conditions rather than unambiguously proceeding straight to a test for a particular condition.

Alexander, C., and J. Wyeth (1994), "Cointegration and market integration: An application to the Indonesian rice market", Journal of Development Studies 30:303–328.

Alexander, C., and J. Wyeth (1995), "Causality testing in models of spatial market integration: A comment on an article by Stefan Dercon", Journal of Development Studies 32:144–146.

Alston, J.M. (1986), "An analysis of growth of U.S. farmland prices, 1963–82", American Journal of Agricultural Economics 68:1–9.

Ardeni, P.G. (1989), "Does the law of one price really hold for commodity prices?", American Journal of Agricultural Economics 71:661–669.

Ashley, R., C.W.J. Granger and R.L. Schmalensee (1980), "Advertising and aggregate consumption: An analysis of causality", Econometrica 48:1149–1168.

Baffes, J. (1991), "Some further evidence on the law of one price: The law of one price still holds", American Journal of Agricultural Economics 73:1264–1273.

Barrett, C.B. (1996), "Market analysis methods: Are our enriched toolkits well-suited to enlivened markets?", American Journal of Agricultural Economics 78:825–829.

Baulch, R.J. (1994), "Spatial price equilibrium and food market integration", Ph.D. dissertation (Stanford University).

Baulch, R.J. (1997), "Transfer costs, spatial arbitrage, and testing for food market integration", American Journal of Agricultural Economics, 79:477–487.

Benirschka, M., and J.K. Binkley (1994), "Land price volatility in a geographically dispersed market", American Journal of Agricultural Economics 76:185–195.

Benson, B.L., and M.D. Faminow (1990), "Geographic price interdependence and the extent of economic markets", Economic Geography 66:47–66.

Benson, B.L., M.D. Faminow and T.J. Fik (1992), "Conduct in spatial markets: An empirical analysis of spatial pricing behavior", Papers in Regional Science 71:15–30.

Benson, B.L., M.D. Faminow, M.H. Maquis and D.G. Sauer (1994a), "The impact of provincial marketing boards on price relations and pricing dynamics in the North American slaughter hog market", Applied Economics 26:677–688.

Benson, B.L., M.D. Faminow, M.H. Maquis and D.G. Sauer (1994b), "Intra-national effects of a countervailing duty on the United States/Canadian hog market", Review of Agricultural Economics 16:187–201.

Bessler, D.A., and S.W. Fuller (1994), "Cointegration between U.S. wheat markets", Journal of Regional Science 33:491–501.

Billups, S.C., S.P. Dirkse and M.C. Ferris (1997), "A comparison of large scale mixed complementarity problem solvers", Computational Optimization and Applications 7:3–25.

Blank, S.C., and B.H. Schmiesing (1988), "Modeling of agricultural markets and prices using causality and path analysis", North Central Journal of Agricultural Economics 10:35–48.

Blyn, G. (1973), "Price series correlation as a measure of market integration", Indian Journal of Agricultural Economics 28:56–59.

Bredahl, M.E., W. Meyers and K.J. Collins (1979), "The elasticity of foreign demand for U.S. agricultural products: The importance of the price transmission elasticity", American Journal of Agricultural Economics 61:58–63.

Bressler, R.G., and R.A. King (1970), Markets, Prices and Interregional Trade (John Wiley and Sons, New York).

Brorsen, B.W., J.-P. Chavas, W.R. Grant and A.W. Ngenge (1985), "Spatial and temporal relationships among selected U.S. grain markets", North Central Journal of Agricultural Economics 7:1–10.

Buccola, S.T. (1989), "Pricing efficiency in agricultural markets: Issues, methods, and results", Western Journal of Agricultural Economics 14:111–121.

Cassel, G. (1918), "Abnormal deviations in international exchanges", Economic Journal 28:413–415.

Chambers, R.G., and R.E. Just (1979), "A critique of exchange rate treatment in agricultural trade models", American Journal of Agricultural Economics 61:249–257.

Cooley, T.F., and S.F. LeRoy (1985), "A theoretical macroeconometrics: A critique", Journal of Monetary Economics 16:283–308.

Crouhy-Veyrac, L., M. Crouhy and J. Melitz (1982), "More about the law of one price", European Economic Review 18(3):325–344.

Cummings, R.W., Jr. (1967), Pricing Efficiency in the Indian Wheat Market (Impex, New Dehli, India).

Currie, J.R. (1995), "The geographical extent of the market: Theory and applications to the U.S. petroleum markets", Working paper (University of Chicago).

Dahlgran, R.A., and S.C. Blank (1992), "Evaluating the integration of contiguous discontinuous markets", American Journal of Agricultural Economics 74:469–479.

Davutyan, N., and J. Pippenger (1990), "Testing purchasing power parity: Some evidence of the effects of transactions costs", Econometric Reviews 9:211–240.

Dercon, S. (1995), "On market integration and liberalisation: Method and application to Ethiopia", Journal of Development Studies 32:112–143.

Dixit, A.K., and V. Norman (1980), Theory of International Trade (Cambridge University Press, Cambridge).

Dries, M.A., and L.J. Unnevehr (1990), "Influence of trade policies on price integration in the world beef market", Agricultural Economics 4:73–89.

Ejiga, N.O.O. (1977), "Economic analysis of storage, distribution, and consumption of cowpeas in Northern Nigeria", Ph.D. dissertation (Cornell University).

Engle, R.F., and C.W.J. Granger (1987), "Co-integration and error correction: Representation, estimation and testing", Econometrica 55:251–276.

Enke, S.A. (1951), "Equilibrium among spatially separated markets: Solution by electrical analogue", Econometrica 19:40–47.

Faminow, M.D., and B.L. Benson (1990), "Integration of spatial markets", American Journal of Agricultural Economics 72:49–62.

Ferris, M.C., and J.S. Pang (1997), "Engineering and economic applications of complementarity problems", SIAM Review 39:669–713.

Garbade, K.D., and W. Silber (1979), "Dominant and satellite markets: A study of dually-traded securities", Review of Economics and Statistics 61:455–460.

Gardner, B.L., and K.M. Brooks (1994), "Food prices and market integration in Russia", American Journal of Agricultural Economics 76:641–646.

Goletti, F. (1993), "The effects of supply shocks on market integration. An application to Bangladesh rice markets" (International Food Policy Research Institute, Washington, DC, USA).

Goletti, F. (1994), "The changing public role in a rice economy approaching self-sufficiency: The case of Bangladesh", Research Report 98 (International Food Policy Research Institute, Washington, DC).

Goletti, F., and S. Babu (1994), "Market liberalization and integration of maize markets in Malawi", Agricultural Economics 11:311–324.

Goletti, F., and E. Christina-Tsigas (1995), "Analyzing market integration", in: G.J. Scott, ed., Prices, Products and People: Analyzing Agricultural Markets in Developing Countries (Lynne Rienner, Boulder, CO).

Goletti, F., R. Ahmed and N. Farid (1995), "Structural determinants of market integration: The case of rice markets in Bangladesh", The Developing Economies, 33:185–202.

Goodwin, B.K. (1988), "Empirically testing the law of one price in an international commodity market: A rational expectations approach", Ph.D. dissertation (North Carolina State University, Raleigh, NC).

Goodwin, B.K. (1992a), "Multivariate cointegration tests and the law of one price in international wheat markets", Review of Agricultural Economics 14:117–124.

Goodwin, B.K. (1992b), "Multivariate cointegration tests and the law of one price: A clarification and correction", Review of Agricultural Economics 14:337–338.

Goodwin, B.K., and T.J. Grennes (1998), "Tsarist Russia and the world wheat market", Explorations in Economic History 35:405–430.

Goodwin, B.K., T.J. Grennes and C. McCurdy (1999), "Spatial price dynamics and integration in Russian food markets", Journal of Policy Modeling, forthcoming.

Goodwin, B.K., T. Grennes and M. Wohlgenant (1990a), "Testing the law of one price when trade takes time", Journal of International Money and Finance 9:21–40.

Goodwin, B.K., T. Grennes and M. Wohlgenant (1990b), "A revised test of the law of one price using rational price expectations", American Journal of Agricultural Economics 72:682–693.
Goodwin, B.K., and F. Ortalo-Magné (1992), "The capitalization of wheat subsidies into agricultural land values", Canadian Journal of Agricultural Economics 40:37–54.
Goodwin, B.K., and T.C. Schroeder (1990), "Testing perfect spatial market integration: An application to regional U.S. cattle markets", North Central Journal of Agricultural Economics 12:173–186.
Goodwin, B.K., and T.C. Schroeder (1991a), "Price dynamics in international wheat markets", Canadian Journal of Agricultural Economics 39:237–254.
Goodwin, B.K., and T.C. Schroeder (1991b), "Cointegration tests and spatial market linkages in regional cattle markets", American Journal of Agricultural Economics 73:452–464.
Gordon, D.V., J.E. Hobbs and W.A. Kerr (1993), "A test for price integration in the EC lamb market", Journal of Agricultural Economics 44:126–134.
Granger, C.W.J. (1969), "Investigating causal relations by econometric models and cross-spectral methods", Econometrica 37:424–438.
Granger, C.W.J. (1980), "Testing for causality: A personal viewpoint", Journal of Economics Dynamics and Control 2:329–352.
Granger, C.W.J. (1988), "Some recent developments in a concept of causality", Journal of Econometrics 39:199–211.
Granger, C.W.J., and C.M. Elliott (1997), "A fresh look at wheat prices and markets in the eighteenth century", Economic History Review 20:257–265.
Gupta, R.C. (1973), Agricultural Prices in a Backward Economy (National, Dehli, India).
Gupta, S., and R.A.E. Mueller (1982), "Analyzing the pricing efficiency in spatial markets: Concept and applications", European Review of Agricultural Economics 9:301–312.
Harriss, B. (1979), "There is method in my madness: Or is it vice versa? Measuring agricultural market performance", Food Research Institute Studies 17:197–218.
Hayenga, M.L., S.R. Koontz and T.C. Schroeder (1996), "Definition of regional cattle procurement markets", GIPSA-RR-96-1, Grain Inspection, Packers and Stockyards Administration, USDA, Washington, DC.
Heytens, P.J. (1986), "Testing market integration", Food Research Institute Studies 20:24–41.
Higginson, N., M. Hawkins and W. Adamowicz (1988), "Pricing relationships in interdependent North American hog markets: The impact of the countervailing duty", Canadian Journal of Agricultural Economics 36:501–518.
Horowitz, I. (1981), "Market definition in antitrust analysis: A regression-based approach", Southern Economic Journal 48:1–16.
Jasdanwalla, Z.Y. (1966), Marketing Efficiency in Indian Agriculture (Allied Publishers Private Ltd., Bombay, India).
Johansen, S. (1988), "Statistical analysis of cointegration vectors", Journal of Economic Dynamics and Control 12:231–254.
Johansen, S., and K. Juselius (1990), "The full information maximum likelihood procedure for inference on cointegration – with application to the demand for money", Oxford Bulletin of Economics and Statistics 52:169–210.
Jordan, K.H., and J.J. VanSickle (1995), "Integration and behavior in the U.S. winter market for fresh tomatoes", Journal of Agricultural and Applied Economics 27:127–137.
King, R.A., ed. (1963), "Interregional competition research methods" (Agricultural Policy Institute, North Carolina State University, Raleigh, NC).
King, R.A., and F.S. Ho (1972), "Reactive programming: A market simulating spatial equilibrium algorithm", Economics Research Report No. 21 (Department of Economics, North Carolina State University, Raleigh, NC).
Klein, C., E.J. Rifkin and N.D. Uri (1985), "A note on defining geographic markets", Regional Science and Urban Economics 15:109–119.
Koontz, S.R., P. Garcia and M.A. Hudson (1990), "Dominant-satellite relationships between live cattle cash and futures markets", Journal of Futures Markets 10:123–136.

Labys, W.C., T. Takayama and N.D. Uri (1989), Quantitative Methods for Market-oriented Economic Analysis over Space and Time (Avebury, Gower Publishing, Hants, England).

Leamer, E.E. (1985), "Vector autoregressions for causal inference?", Carnegie-Rochester Conference Series on Public Policy 22:255–304.

Leamer, E. (1994), "Trade, wages, and revolving door ideas", NBER Working Paper No. 4716.

Lele, U.J. (1967), "Market integration: A study of sorghum prices in Western India", Journal of Farm Economics 49:147–159.

Lele, U.J. (1971), "Food grain marketing in India: Private performance and public policy" (Cornell University Press, Ithaca, New York).

Loveridge, S. (1991), "Marketing in Rwanda – imports and infrastructure", Food Policy 16:95–104.

Lutz, C., A.V. Tilburg and B. Van Der Camp (1995), "The process of short- and long-term price integration in the Benin maize market", European Review of Agricultural Economics 22:191–212.

Marshall, A. (1890), Principles of Economics, 8th edn. (Macmillan Company, New York).

McNew, K.P., and P.L. Fackler (1997), "Testing market equilibrium: Is cointegration informative?", Journal of Agricultural and Resource Economics 22:191–207.

Mendoza, M.S., and M.W. Rosegrant (1992), "The dynamics and efficiency of spatial arbitrage and integrated commodity markets", Presented at the Annual Meeting of the American Agricultural Economics Association, Baltimore, MD.

Mendoza, M.S., and M.W. Rosegrant (1995a), "Pricing behavior in Philippine corn markets: Implications for market efficiency", Research Report 101 (International Food Policy Research Institute, Washington, DC).

Mendoza, M.S., and M.W. Rosegrant (1995b), "Pricing conduct of spatially differentiated markets", in: G.J. Scott, ed., Prices, Products and People: Analyzing Agricultural Markets in Developing Countries (Lynne Rienner, Boulder, CO).

Michael, P., A.R. Nobay and D. Peel (1994), "Purchasing power parity yet again: Evidence from spatially separated commodity markets", Journal of International Money and Finance 13:637–657.

Mill, J.S. (1848), Principles of Political Economy (Longmans and Sons, London) (reprinted 1929).

Mjelde, J.W., and M.S. Paggi (1989), "An empirical analysis of interregional price linkages", Journal of Regional Science 29:171–190.

Mohendru, I.D. (1937), "Some factors affecting the price of wheat in the Punjab", Publication No. 49 (Board of Economics Inquiry, Punjab Government).

Mokhtari, M., and F. Rassekh (1989), "The tendency towards factor price equalization among OECD countries", Review of Economics and Statistics 71:636–642.

Monke, E., and T. Petzel (1984), "Market integration: An application to international trade in cotton", American Journal of Agricultural Economics 66:481–487.

Myers, R.J., R.R. Piggott and W.G. Tomek (1990), "Estimating sources of fluctuations in the Australian wool market: An application of VAR methods", Australian Journal of Agricultural Economics 34:242–262.

Obstfeld, M., and A.M. Taylor (1997), "Nonlinear aspects of goods-market arbitrage and adjustment; Heckscher's commodity points revisited", Journal of the Japanese and International Economies 11:441–479.

Officer, L. (1982), Purchasing Power Parity and Exchange Rates: Theory, Evidence, and Relevance (JAI Press, Greenwich, CT).

Officer, L. (1986), "The law of one price cannot be rejected; Two tests based on the tradable/nontradable goods dichotomy", Journal of Macroeconomics 8:159–182.

Palaskas, T.B., and B. Harriss-White (1993), "Testing market integration: New approaches with case material from the West Bengal food economy", Journal of Development Studies 30:1–57.

Prakash, G. (1996), "Pace of market integration", Working Paper (Department of Economics, Northwestern University, Evanston, IL).

Protopapadakis, A.A., and H.R. Stoll (1986), "The law of one price in international commodity markets: A reformulation and some formal tests", Journal of International Money and Finance 5(3):335–360.

Ravallion, M. (1986), "Testing market integration", American Journal of Agricultural Economics 68:102–109.

Ricardo, D. (1817), Principles of Political Economy and Taxation (Dent, London) (reprinted 1911).

Richardson, D.J. (1978), "Some empirical evidence on commodity arbitrage and the law of one price", Journal of International Economics 8:341–351.

Roe, T., M. Shane and D. Huu-Vo (1986), "Price responsiveness of world grain markets", USDA Technical Publication No. 1720.

Roll, R. (1979), "Violations of purchasing power parity and their implications for efficient international commodity markets", in: M. Sarnat and G. Szego, eds., International Finance and Trade (Ballinger, Cambridge).

Samuelson, P.A. (1949), "International factor price equalization once again", Economic Journal 59:181–197.

Samuelson, P.A. (1952), "Spatial price equilibrium and linear programming", American Economic Review 48:283–303.

Sexton, R.J., C.L. Kling and H.F. Carman (1991), "Market integration, efficiency of arbitrage and imperfect competition: Methodology and application to U.S. celery", American Journal of Agricultural Economics 73:568–580.

Silvapulle, P., and S. Jayasuriya (1994), "Testing for Philippines rice market integration: A multiple cointegration approach", Journal of Agricultural Economics 45:369–380.

Slade, M.E. (1986), "Exogeneity tests of market boundaries", Journal of Industrial Economics 34:291–303.

Slaughter, M.J., R.E. Hall, S.J. Davis and R.H. Topel (1993), "International trade and American wages in the 1980s: Giant sucking sound or small hiccup?", Brookings Papers on Economic Activity, Special Issue 2:161–210.

Spiller, P.T., and C.J. Huang (1986), "On the extent of the market: Wholesale gasoline in the Northeastern United States", Journal of Industrial Economics 35:131–145.

Spiller, P.T., and R.O. Wood (1988), "The estimation of transactions costs in arbitrage models", Journal of Econometrics 39:309–326.

Stigler, G.J. (1966), The Theory of Price, 3rd edn. (MacMillan, New York).

Stigler, G.J., and R.A. Sherwin (1985), "The extent of the market", Journal of Law and Economics 28:555–586.

Takayama, T., and G.G. Judge (1964a), "Spatial equilibrium and quadratic programming", Journal of Farm Economics 46:67–93.

Takayama, T., and G.G. Judge (1964b), "An intertemporal price equilibrium model", Journal of Farm Economics 46:349–365.

Takayama, T., and G.G. Judge (1971), Spatial and Temporal Price Allocation Models (North-Holland, Amsterdam).

Teklu, T., J. von Braun and E. Zaki (1991), "Drought and famine relationships in Sudan: Policy implications", Research Report 88 (International Food Policy Research Institute, Washington, DC).

Thompson, S.R., J.S. Eales and R.J. Hauser (1990), "An empirical analysis of cash and futures grain price relationships in the North Central region", North Central Journal of Agricultural Economics 12:241–254.

Thompson, R.L. (1989), "Spatial and temporal price equilibrium agricultural models", in: Labys, Takayama and Uri (1989).

Timmer, C.P. (1987), "Corn marketing, Chapter 8", in: C.P. Timmer, ed., The Corn Economy of Indonesia (Cornell University Press, Ithaca, NY).

Tomek, W.G., and R.J. Myers (1993), "Empirical analyses of agricultural commodity prices: A viewpoint", Review of Agricultural Economics 15:181–202.

Tramel, T.E., and A.D. Seale, Jr. (1959), "Reactive programming of supply and demand relations – applications to fresh vegetables", Journal of Farm Economics 41:1012–1022.

Tschirley, D.L. (1995), "Using microcomputer spreadsheets for spatial and temporal price analysis", in: G.J. Scott, ed., Prices, Products and People: Analyzing Agricultural Markets in Developing Countries (Lynne Rienner, Boulder, CO).

Uri, N.D., G.V. Chomo, R. Hoskin and B. Hyberg (1993), "The integration of the market for soybeans and soybean products", Food Policy 18:200–213.

Uri, N.D., J. Howell and E.J. Rifkin (1985), "On defining geographic markets", Applied Economics 17:959–977.

Webb, P., J. von Braun and Y. Yohannos (1992), "Famine in Ethiopia: Policy implications of coping failure at national and household levels", Research Report 97 (International Food Policy Research Institute, Washington, DC).

Weinschenck, G., W. Henrichsmeyer and F. Aldinger (1969), "The theory of spatial equilibrium and optimal location in agriculture: A survey", Review of Marketing and Agricultural Economics 37:3–70.

Werden, G.J., and L.M. Froeb (1993), "Correlation, causality, and all that jazz: The inherent shortcomings of price tests for antitrust market delineation", Review of Industrial Organization 8:329–353.

Williams, C., and R. Bewley (1993), "The transmission of price information at Queensland cattle auctions", Australian Journal of Agricultural Economics 37:33–55.

Williams, J., and B. Wright (1991), Storage and Commodity Markets (Cambridge University Press, Cambridge).

Williamson, J. (1986), "Target zones and the movement of the dollar", Brookings Papers on Economic Activity 17:165–174.