THE INTERNATIONAL PRICE TRANSMISSION IN STOCK INDEX FUTURES MARKETS

JIAN YANG and DAVID A. BESSLER*

This study explores dynamic price relationships among nine major stock index futures markets, combining an error-correction model with directed acyclic graph (DAG) analysis. DAG-based innovation accounting results show that the Japanese market is isolated from other major stock index futures markets. The United States and the United Kingdom appear to share leadership roles in stock index futures markets. The UK and German markets rather than the U.S. exert significant influences on most European markets, which indicates a pattern of regional integration in Europe. Innovation accounting results based on widely used Choleski decomposition are found to be seriously misleading. (*JEL* G15, C32)

I. INTRODUCTION

Numerous studies have investigated market linkages and price transmission mechanisms in major international equity markets, employing the analytical framework of the vector autoregression (VAR) or its variant, the error-correction model (ECM).[1] Studies such as Von Furstenberg and Jeon (1989), Eun and Shim (1989), and Koch and Koch (1991) focus on the short-run dynamic pattern of price transmission; others like Taylor and Tonks (1989) and Francis and Leachman (1998) are primarily interested in the long-run pattern of price transmission. More recently, an increasing number of studies explore both long- and short-run patterns of price transmission. Included in this last set are the works of Malliaris and Urrutia (1992), Arshanapalli and Doukas (1993), Masih and Masih (2001), and Bessler and Yang (2003), among others.

This study extends the examination of international price transmission to stock index futures markets. The article contributes to the existing literature in three aspects. First, a relatively new empirical framework is applied to allow for inferences of price transmission at three different time horizons: instantaneous, the short run, and the long run. Building on recent advances in statistical analysis of causal modeling using directed acyclic graphs (DAGs) as in Spirtes et al. (2000), Pearl (1995, 2000), and Swanson and Granger (1997), this study is able to explore the contemporaneous causal pattern underlying the correlations among market innovations. The existence of strong contemporaneous correlations among market innovations has been well documented in the United States and international stock markets by Agmon (1972), Eun and Shim (1989), Koch and Koch (1991), Housbrouk (1995), and Bessler and Yang (2003). It is also well recognized by Agmon (1972, 849) and Eun and Shim (1989, 246) that contemporaneous correlations among market innovations reflect the phenomenon that new information in one market is

ABBREVIATIONS

DAG: Directed Acyclic Graph
ECM: Error-Correction Model
SPI: Share Price Index
VAR: Vector Autoregression

---

*We thank three anonymous referees, session participants at the 2002 Financial Management Association and 2002 Southwestern Finance Association annual meetings, and seminar participants at Texas A&M University for helpful comments. An earlier version of the paper was awarded 2002 Best Paper in International Finance Award by Southwestern Finance Association. We also thank Michele Zinn for her editorial comments.

Yang: Department of Accounting, Finance and Information Systems, Prairie View A&M University, Prairie View, TX 77446. Phone 1-936-857-4011, Fax 1-936-857-2797, E-mail jian_yang@pvamu.edu
Bessler: Department of Agricultural Economics, Texas A&M University, College Station, TX 77843. Phone 1-979-845-3096, Fax 1-979-862-1563, E-mail d-bessler@ tamu.edu

[1] Another strand of the literature, which is not pursued in this study, explores stock volatility transmission. See, for example, Hamao et al. (1990).

Economic Inquiry
(ISSN 0095-2583)
Vol. 42, No. 3, July 2004, 370–386

DOI: 10.1093/ei/cbh067

transmitted and shared by other markets in contemporaneous time, due to immediate response to price changes between markets. However, more in-depth analysis on exactly how instantaneous price transmission among market innovations is conducted in international equity markets has not yet been well addressed in the existing literature. Although Bessler and Yang (2003) touch on the issue, the necessity of imposing constraints in the spirit of the block-recursive structure noted by Koch and Koch (1991) in the DAG analysis of VAR innovations is proposed and discussed thoroughly in this study.

Second, innovation accounting analysis is more thoroughly explored in the study. Innovation accounting tools (i.e., impulse response analysis and forecast error variance decomposition) have been commonly used to summarize the dynamic pattern of price transmission among international financial markets. The importance of the factorization of innovations (i.e., VAR residuals) in yielding sound inference has been well acknowledged theoretically by Bernanke (1986), Sims (1986), and Swanson and Granger (1997). The application of the DAG technique, as discussed in Swanson and Granger (1997) and explained in the next section, is further key to innovation accounting analysis. In this study, the instantaneous price transmission pattern between market innovations (as identified by the DAG analysis) provides a data-determined solution to the basic problem of orthogonalization of residuals from the ECM and thus is critical to impulse response analysis or forecast error variance decompositions. Swanson and Granger (1997) argue that compared to the Choleski decomposition, the DAG-based structural decomposition is sensible but not subjective, because it allows for the properties exhibited by the data. Although several recent studies, such as those by Bessler and Yang (2003), Bessler et al. (2003), Haigh and Bessler (forthcoming), and Yang (2003), have used the DAG-based structural decomposition in a similar setting, the study is the first attempt responding to the suggestion by Swanson and Granger (1997, 364) of investigating the empirical implications of the DAG-based contemporaneous causal modeling.

The problems of implementing the Choleski factorization in the literature have been well recognized. These include the often unrealistic assumption of the existence of a recursive structure and/or the inability of research workers to identify the correct recursive structure (if such exists) as discussed by Bernanke (1986), Sims (1986), and Swanson and Granger (1997). An arbitrary ordering of variables assumes that correlations between innovations are attributed to the variables placed higher in the Choleski ordering, which may be particularly misleading in the case of existence of strong correlations between VAR residuals (as in this study). Challenging many previous studies, we demonstrate empirically here that the widely used Choleski decomposition, in contrast to the DAG-based structural decomposition, results in seriously misleading innovation accounting results.

Finally, to the best of our knowledge, this is the first study to comprehensively examine the price transmission mechanism across international stock index futures markets (particularly in the context of modeling with a VAR or its variant, an ECM), which have been in existence in more than 30 countries in the world. Arguably, exploiting international equity broad market relationships for the benefit of trading can be better served through stock index futures trading. Typically, stock market indexes themselves are not directly investable, nor tradable through cash market transactions. Replicating the stock market index through buying constituent stocks involves a greater initial investment, longer time to implement, higher transaction costs, and tracking errors problems. Thus, stock index futures trading is preferred by investors, particularly those engaged in speculative transactions. In this sense, international equity market price relationships, as reflected in the stock index futures markets, are more relevant to active traders. Use of stock index futures data could also provide additional insights on the analysis of international equity market linkages because the prices of stock index futures almost consistently lead the stock index movements and thus may perform a better informational role as noted in Kawaller et al. (1987).

The organization of the article is as follows. Section II discusses the proposed methodology. Section III describes the data and some related issues. Section IV presents the empirical results. Section V concludes.

II. EMPIRICAL FRAMEWORK

This section presents an empirical framework that will facilitate our study on the long-run, short-run, and instantaneous price transmission patterns in international stock index futures markets. For more general discussion on the DAG, see Spirtes et al. (2000), Pearl (1995, 2000), and Swanson and Granger (1997). For more details on econometric analysis of the long-run and the short-run structures, see Johansen and Juselius (1994).

Cointegration, ECM, and Innovation Accounting

Let X_t denote a vector that includes p nonstationary prices ($p = 9$ in this study). Assuming existence of cointegration, the data-generating process of X_t can be appropriately modeled in an ECM with $k-1$ lags (which is derived from a level VAR with k lags):

$$(1) \qquad \Delta X_t = \Pi X_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \Delta X_{t-i} + \mu + e_t (t = 1, \ldots, T)$$

$$(2) \qquad e_t \sim iid(0, \Sigma)$$

where $\Pi = \alpha\beta'$.

The long-run pattern of price transmission is examined by testing the number of cointegration relations (r). Here, the primary interest lies in whether there is a price transmission mechanism sufficiently at work so that certain long-run price relationships may be maintained. The rank of Π determines the number of cointegrating vectors, which can be tested as follows:

$$(3) \qquad H(r){:}\Pi = \alpha\beta'.$$

Trace tests as developed by Johansen (1991) can be used to test this hypothesis. However, typically only a very few (e.g., one) cointegrating vectors are found to exist among a number of stock price series (e.g., nine price series) as seen in Francis and Leachman (1998), Masih and Masih (2001), and Bessler and Yang (2003). In such a case, the long-run equilibrium relationship may not be strongly constrained, which explains the rather loose comovements of the major stock market prices. It would be of interest to examine how prices adjust interactively among themselves under the constraint of the identified long-run equilibrium price relationships (if any).

The short-run dynamic pattern of price transmission involves two parts, α and Γ_i. The parameter α defines the short-run adjustment to the long run relations, and the parameters $(\Gamma_1, \ldots, \Gamma_{k-1})$ define the short-run adjustment to the changes of the process. However, it is well recognized that like the standard VAR, the individual coefficients of the ECM are hard to interpret, particularly the short-run dynamics (Γ) (note that the ECM may be equivalent to a levels VAR). Furthermore, Toda and Phillips (1993, 1388) argued that Granger causality tests are fraught with many complications when there are stochastic trends and cointegration in the system. Unless so-called sufficient cointegration rank conditions are met, the chi-square statistics for weak exogeneity tests regarding the parameter (α) may be invalid, and thus any causal inference in the Granger sense is unwarranted. Obviously, under such cases, innovation accounting may be the best description of the short-run dynamic structure as shown by Sims (1980), Lutkepohl and Reimers (1992), and Swanson and Granger (1997). In this study, the estimated ECM is reexpressed as a levels VAR to impose cointegration constraints, which Phillips (1998) has recently proven to be crucial in yielding consistent results on impulse responses and forecast error variance decompositions. Impulse response analysis and forecast error variance decomposition are then conducted based on the equivalent levels VAR to summarize the short-run dynamic linkages among various markets.

So far, the basic problem of factorization of residuals from the ECM remains unsolved. The method for treating contemporaneous innovation correlation is critical to innovation accounting. Earlier VAR-type analyses commonly rely on a Choleski factorization to achieve a just-identified system in contemporaneous time. The main problem with the Choleski factorization is that the mechanical imposition of (contemporaneous) recursive causation may not be valid as shown by Bernanke (1986), Sims (1986), and Swanson and Granger (1997). A more recent approach to dealing with the contemporaneous correlation problem is the so-called structural factorization following the approaches of Bernanke (1986) and Sims (1986), which allows for nonrecursive structure of (contemporaneous) causation. The structural factorization gives researchers a general approach to modeling contemporaneous structure. Its use in the literature, however, is still primarily reliant on subjective or theory-based information for specifying contemporaneous causal flow. Following Swanson and Granger (1997), this study adopts a data-determined approach (i.e., the DAG technique) to explore the contemporaneous causal structure of innovations, which meanwhile provides information on the instantaneous price transmission pattern.

Directed Graph Modeling

The information on the instantaneous price transmission pattern may be explored by examining the causal (and independence) relationships of innovations in contemporaneous time across markets, based on the variance–covariance matrix of innovations (i.e., residuals from the ECM). In this study, the DAG technique is used in providing data-based evidence on causal ordering of economic variables in contemporaneous time (t), assuming the information set (Ω_{t-1}) is causally sufficient.

Essentially, a directed graph is an assignment of causal flows (or lack thereof) among a set of variables (vertices) based on observed correlations and partial correlations. Each pair of variables is characterized by an edge relationship representing the causal relationship (or lack thereof) between them. In the context of the DAG used in this study, there are five applicable cases for an edge relationship: (1) no edge ($X \quad Y$), which indicates (conditional) independence between two variables; (2) undirected edge (X—Y), which signifies a covariance that is given no particular causal interpretation; (3) directed edges ($Y \rightarrow X$), which suggests that a variation in Y with all other variables held constant, produces a (linear) variation in X that is not mediated by any other variable in the system; (4) directed edges ($X \rightarrow Y$); (5) bidirected edges ($X \leftrightarrow Y$), which indicates the bidirection of causal interpretation between the two variables.

Spirtes et al. (2000) provide an algorithm (PC algorithm) for removing edges between markets and directing instantaneous causal flows of information between markets. The algorithm removes edges from the complete undirected graph by first checking for (unconditional) correlations between pairs of variables. Edges connecting variables having zero correlation are removed. Remaining edges are then checked for first-order partial correlation (correlation between two variables conditional on a third variable) equal to zero. Similarly, edges connecting variables having zero first-order conditional correlation are removed. Edges that survive this check of first-order conditional correlation are then checked against zero second-order conditional correlation, and so on. The algorithm continues to check up to N–2-order conditional correlation. In applications, Fisher's z-statistic is used to test whether conditional correlations are significantly different from zero.

The conditioning variable(s) on removed edges between two variables is defined as the *sepset* of the variables whose edges have been removed (for vanishing zero-order conditioning information [unconditional correlation] the *sepset* is the empty set). The remaining edges are then directed by considering triples X–Y–Z, such that X and Y are adjacent as are Y and Z, but X and Z are not adjacent. Direct the (remaining) edges between triples X–Y–Z as $X \rightarrow Y \leftarrow Z$ if Y is not in the *sepset* of X and Z. Further, if $X \rightarrow Y$, Y and Z are adjacent, X and Z are not adjacent, and there is no arrowhead at Y, then Y–Z should be positioned as $Y \rightarrow Z$. Finally, if there is a directed path from X to Y and an edge between X and Y, then X–Y should be positioned as $X \rightarrow Y$. The PC algorithm, as discussed, is programmed in the software TETRAD II as described in Scheines et al. (1994).

III. DATA ISSUES

The data used in this study consist of daily nearby futures prices of nine major stock index futures markets. They include stock index futures markets in Australia, Japan, Hong Kong, Germany, France, United Kingdom, Switzerland, United States, and Canada. The criteria of selecting these markets consider both their significant roles in international stock markets and maturity and liquidity of stock index futures markets. Specifically, the stock index futures markets under study are the All Ordinaries share price index futures contracts (Australia) traded on the Sydney Futures Exchange (SFE), the Nikkei 225 stock average futures contracts (Japan) traded on the Osaka Securities Exchange (OSE), the Hang Seng index futures contracts (Hong Kong) traded on the Hong Kong Futures Exchange

(HKFE), the CAC 40 stock index futures contracts (France) traded on the Matif, the Frankfurt DAX stock index futures contracts (Germany) traded on the EUREX Exchange, the Swiss market index futures contracts (Switzerland) traded on the EUREX Exchange, the FTSE 100 Index futures contracts (UK) traded on the London International Financial Futures Exchange (LIFFE), the S&P 500 Index futures contracts (U.S.) traded on the Chicago Mercantile Exchange (CME), and the Toronto 35-stock index futures contracts (Canada) traded on the Toronto Futures Exchange (TFE).[2] All stock index futures prices are nearby futures settlement prices and are obtained both in local currencies and in U.S. dollars. The Datastream databank provides all the data. The sample period is from 1 January 1994 through 31 December 2000, yielding a total of 1891 observations.

Following the convention discussed by Eun and Shim (1989), Koch and Koch (1991), and Arshanapalli and Doukas (1993), the analysis in this study is conducted based on the daily data matched on the same calendar day. For such analysis, the problem of international trading nonsynchronism, that is, international stock index and stock index futures markets operate in different time zones, is well acknowledged in the literature.[3] Based on Battley (2000), Figure 1 lists the floor trading time for each of the nine futures markets during the study period.[4] The three Asia-Pacific markets (Australia, Japan, and Hong Kong) are open when the European (Germany, Switzerland, France, and the United Kingdom) and North American markets (the United States and Canada) are closed. The exception is an overlap of 0.75 hour between the Hong Kong and German and Swiss markets, which turns out to make little difference in the DAG analysis whether or not it is ignored.

Eun and Shim (1989) tackle the problem of international trading nonsynchronism by first carefully examining the structure of trading time differences and then explicitly incorporating its implications into the interpretation of empirical results. In this study, in addition to following Eun and Shim's (1989) recommendation, a new solution is further provided based on our application of directed graphs. Specifically, such a restriction is imposed that market A cannot influence market B in contemporaneous time if the latter (B) is closed before the former (A) opens. The time sequence of opening and closing in these futures markets suggests the following restrictions. Specifically,

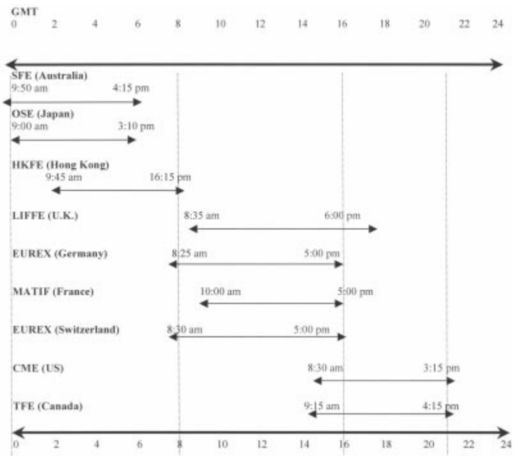
---

[2] The Canadian stock index futures price series is constructed by a combination of Toronto 35 (01/01/94–11/30/99) and the S&P/TSE 60 (12/01/99–12/31/00) stock index futures price series. The latter is designed as the replacement of the former. As will be discussed shortly, a dummy variable is considered to capture the possible one-time structural break on the market interrelationship. Also, the SFE in Australia has recently launched a new futures contract, the S&P/ASX 200 share price index (SPI 200) futures, as the replacement of the All Ordinaries share price index (SPI) futures. Because September 2001 is chosen as the cut-off date for the existing SPI futures, the price data for the SPI futures is available during the sample period and consistently used in this study. Nevertheless, the analysis based on the SPI futures price data should be meaningful, because the underlying index for the SPI futures contracts (i.e., the All Ordinaries index) is quite comparable with that for the new SPI 200 futures contracts (i.e., the S&P/ASX 200 index). For example, stocks included in the All Ordinaries index are those of the 250 biggest Australian companies, whereas stocks included in the S&P/ASX 200 index are those of the 200 biggest Australian companies.

[3] Although the use of futures settlement prices is inevitably associated with the nonsynchronous trading problem, there are several reasons supportive of such an analysis. First, although some futures markets have moved substantially toward 24-hour trading, a number of futures markets have not yet accomplished that much. Thus, as illustrated in Figure 1, synchronous trading data are not yet available for studying all these major markets at this time. Second, as pointed out by Eun and Shim (1989, 243), despite the nonsynchronous nature of the data employed, the results of VAR analysis based on the structure of time zone differences can still provide useful insights into the international transmission mechanism of stock index future market movements. Third, unlike the futures prices sampled at any other time during a trading day, the settlement prices play a particularly important role to investors because of the marked-to-market practice of daily settlement in the futures markets.

[4] Three futures markets under study are characterized by moving substantially toward continuously trading markets. One is the All Ordinaries share price index futures market in Australia. The market has electronic trading on SYCOM from 16:40 P.M. to 7:00 A.M. (next day) (local time). The other market is the CAC 40 stock index futures market in France. In addition to the regular floor trading hours, the market also has the morning session (8:00 A.M.–10:00 A.M.) and the evening session (17:00 P.M.-22:00 P.M.). The S&P 500 futures market in the US also has electronic trading on GLOBEX (15:45 P.M.–8:15 A.M. [next day]) on weekdays. Obviously, implications of the extended trading hours on the following analysis of imposing block-recursive structure should be explored and the sensitivity of the DAG results should be addressed. A particularly important point worthy of noting in this matter is that the opening of the extended electronic trading hours (after the regular trading hours) represents the beginning of the next official trading day. The main reason is that the futures settlement prices (as used in this study) are registered and disseminated by the futures clearing houses at the end of regular floor trading hours (in the afternoon each trading day). Also, the volume of trading during the extended hours is much less active than (for example, one-tenth of) that during regular trading hours.

FIGURE 1
Regular Floor Trading Hours in Nine Stock Index Futures Markets



innovations in the Asia-Pacific markets (the first block) cannot be caused by innovations in the European or North American markets (the second block), because the Asia-Pacific markets close in time period t before the European or North American markets open.[5] As will be explained shortly, such restrictions on the directed graph analysis are very similar to the block-recursive structure as emphasized in Koch and Koch (1991, 235) and also consistent with discussions in Von Furstenberg and Jeon (1989, 143), Eun and Shim (1989, 243), and Malliaris and Urrutia (1992, 357).

To understand appropriateness of such restrictions, the key issue is to clarify what a VAR innovation is about. As pointed by Eun and Shim (1989, 246), market innovations from a VAR are unexpected return changes on each market (due to the news) and cannot be predicted by the price information embed in already observed prices of its own and other markets in previous trading days. More specifically, innovations of the first block markets (such as Japan) at time t is totally new, relative to the price information embed in the second block markets (such as the United States) price at time $t - 1$, the (lagged) influence of which on the Japanese market has been allowed for. However, when Japan opens at time t and already observes and incorporates the most recent U.S. price at time $t - 1$, the U.S. market is closed. The innovations on the Japan market at time t cannot be due to the new information from the U.S. market on the same calendar day, which will open after the Japanese market is closed on the same calendar day.

On the other hand, the U.S. innovation could be (insignificantly, partly, or largely) attributable to news from the Japanese market on the same calendar day, depending on the perceived usefulness of new information from the Japanese market. Lin et al. (1994) offer more discussion on this possibility. The contemporaneous causal flow from countries in the first block to countries in the second block may resemble the "lagged spillover" pattern as explored in Hamao et al. (1990, 282–3) and Lin et al. (1994, 508–9), which concerns how stock returns (and/or volatility) in one market may be correlated with the next market to trade that has no or little overlapping trading hours. These researchers argue that such a spillover pattern may present an interesting causal phenomenon across markets that trade sequentially, because the correlation between return innovations of two markets with no overlapping trading hours is predicted not to occur by international asset pricing models. In this study, the contemporaneous causal flow pattern between countries within the same block and between countries across the two blocks is jointly analyzed in the DAG framework, which extends the studies.

Noteworthy, the lagged price transmission mechanism based on already observed prices is what is captured by the coefficients of the lagged explanatory variables in each equation of the ECM (see equation [1]). In other words, the causal influence of the second block markets (e.g., the United States) at time $t - 1$ on the first block markets (e.g., Japan) at time t is taken into consideration by the coefficients of the lagged U.S. market price in the equation

---

[5] The allowance for the extended electronic trading hours on the Australian, French, and U.S. markets, as detailed in note 3, may not justify inclusion of France in the second block. The morning session may be counted as a part of trading on the current trading day and thus produces an overlapped trading of more than one hour between the French and Hong Kong markets. The DAG analysis is performed based on the new restriction that maintains the identities of other markets in the two blocks while no restriction is imposed on the French market. The resulting directed graph is the same as what is presented later. The allowance for the extended electronic trading hours should not affect the identity of the Australian market in the first block and that of the U.S. markets in the second block. This is because the relevant timing, that is, the timing of the sampled prices (i.e., the settlement prices), is unaffected. Also, see the related discussion in note 10 in Koch and Koch (1991, 246–47).

explaining the Japanese market price. Coefficients on lagged prices (not current innovations) measure the influence of the U.S. market (as well as Canada and European markets) on the first block markets, such as Japan (and Australia and Hong Kong).

Finally, there exist several possible structural changes in the data-generating process during the sample period. In particular, the following four cases are identified and addressed in the analysis. First, since 12/01/99, the Canadian futures price is based on S&P/TSE 60 futures contract traded on Montreal Exchange, due to recently ceased trading on TSE 35. This involves a change on the contract specification. However, TSE 30 and S&P/TSE 60 are to a large extent comparable. Second, the date 01/04/99 indicates the starting day for stock index futures contracts traded in France, Germany, and Switzerland to be denominated in terms of the euro due to the establishment of the Economic and Monetary Union in 1999. This may be a possible structural break. However, casual check of the data in local currency terms suggests insignificant change on the data generating process. Third, the CAC 40 experienced a change in the futures specification on 07/01/1998, before it had another change to the Euro currency term on 01/04/99. Fourth, Switzerland also made the contract specification change in 1998. Fifth, Hong Kong experienced the most significant stock market collapse between 10/20/97 and 10/28/97 due to the 1997–98 Asian financial crisis, which resulted in a total cumulative loss of 40% in the Hang Seng index in one week. A dummy variable is defined for each of these cases. The analysis is also performed based on such a model specification and yields similar inference, as presented next.

IV. EMPIRICAL RESULTS

The empirical analysis employs the maximum-likelihood estimation procedure developed by Johansen (1991) and is based on the data in local currency terms. We also conducted robustness checks based on the data in U.S. dollar terms, different significance levels (0.1%, 1%, and 5%), different lags (two to six lags), and different numbers of cointegration ranks (one versus two). We found that the basic inference, as will be reported, is qualitatively unchanged. Allowing for the maximum lag of 15 (time lag of information absorption in three weeks), a VAR with two lags is found adequate to model the data-generating process, based on minimization of the Schwarz information criterion. Trace test results (available on request) show that there exist two cointegrating vectors at the 5% significance level.[6] Also, though some mild GARCH effects are found in the residuals of the ECM, the cointegration conclusion based on the Johansen maximum-likelihood estimation procedure should be quite robust as demonstrated in Gonzalo (1994). Accordingly, throughout the remainder of this article, ECM is studied with imposition of two cointegrating vectors. It is noteworthy that one cointegrating vector (or fewer) is typically found in studies of international equity markets using cash indexes at the 5% significance level as noted by Francis and Leachman (1998), Masih and Masih (2001), and Bessler and Yang (2003). The evidence here may be consistent with more informed futures prices due to their lower transaction costs and thus more active trading.

It is interesting to examine whether a more definitive statement can be made about the nature of the long-run pattern among these nine markets. In particular, it is possible that two cointegrating vectors may arise in the data because two of the markets show stationary prices over time. The null hypothesis is tested that each price series is itself stationary (and thus by itself gives rise to one cointegrating vector). The test statistic is distributed chi-squared with 7 ($=p$–r) degrees of freedom. The result (available on request) shows that the null is rejected for each series at any conventional significance level.

As noted previously, the (short-run) dynamic price transmission pattern among the nine markets can be best summarized through applying innovation accounting techniques to the estimated ECM. The method for

[6] We also studied the number of cointegrating vectors at alternative lags. We find that for all specifications with lags 2–6 periods, there are two cointegrating vectors at the 5% significance level but only one cointegrating vector at the 1% significance level. By contrast, based on the data denominated in U.S. dollars, there exist two cointegrating vectors either at the 1% or the 5% significance level. However, as the Johansen cointegration test has a low power and the time span (seven years in this study) rather than the number of observations is the most important factor in affecting the power of such test (Hakkio and Rush 1991), the 0.05 significance level should be more appropriate. Nevertheless, based on the assumption of one cointegrating vector, we also conducted subsequent DAG analysis and forecast error variance decomposition and found that the basic result is qualitatively the same.

treating contemporaneous innovation correlation is critical to such an analysis. The structural factorization of Bernanke (1986) and Sims (1986) is followed in this study. The innovation vector (υ_t) from the estimated levels VAR model can be written as: $\mathbf{A}\upsilon_t = \varepsilon_t$, where $\mathbf{A}$ is a 9×9 matrix and ε_t is a 9×1 vector of orthogonal shocks. Unlike Choleski factorization, which restricts the **A** matrix to be lower triangular to achieve a just-identified system in contemporaneous time, the DAG given in Spirtes et al. (2000) is applied here to place zeros on the **A** matrix.[7]

Innovations from the ECM (representing these innovations as υ_{it}) give us the contemporaneous innovation correlation matrix, Σ. Equation (4) gives the lower triangular elements of the correlation matrix on innovations ($\hat{v}$) from equation (4). We list abbreviations on each country across the top of the matrix.

$$(4)\Sigma(\hat{\upsilon}_t)$$

$$= \begin{array}{c} \begin{array}{ccccccccc} \mathbf{AUS} & \mathbf{JPN} & \mathbf{HK} & \mathbf{GER} & \mathbf{FRN} & \mathbf{UK} & \mathbf{SWI} & \mathbf{US} & \mathbf{CAN} \end{array} \\ \left[\begin{array}{ccccccccc} 1.0 & & & & & & & & \\ 0.23 & 1.0 & & & & & & & \\ 0.35 & 0.24 & 1.0 & & & & & & \\ 0.18 & 0.15 & 0.28 & 1.0 & & & & & \\ 0.16 & 0.16 & 0.25 & 0.77 & 1.0 & & & & \\ 0.18 & 0.17 & 0.28 & 0.68 & 0.68 & 1.0 & & & \\ 0.18 & 0.14 & 0.21 & 0.71 & 0.63 & 0.62 & 1.0 & & \\ 0.12 & 0.07 & 0.13 & 0.42 & 0.40 & 0.43 & 0.37 & 1.0 & \\ 0.14 & 0.09 & 0.14 & 0.35 & 0.34 & 0.35 & 0.30 & 0.60 & 1.0 \end{array}\right] \end{array}$$

In general, similar to Eun and Shim (1989), the correlations between countries in the same region are higher than those between countries in different regions. It should be noted that this pattern of contemporaneous correlations may generally reflect both the structure of time zone differences and the degree of economic integration between countries as discussed by Eun and Shim (1989, 246). Contrasting with the comparable pairwise correlations in the same regions reported in Eun and Shim (1989), the finding here suggests stronger links between European markets, perhaps due to their ongoing regional economic integration process. Equation (4) is the starting point for the following DAG analysis with TETRAD II.

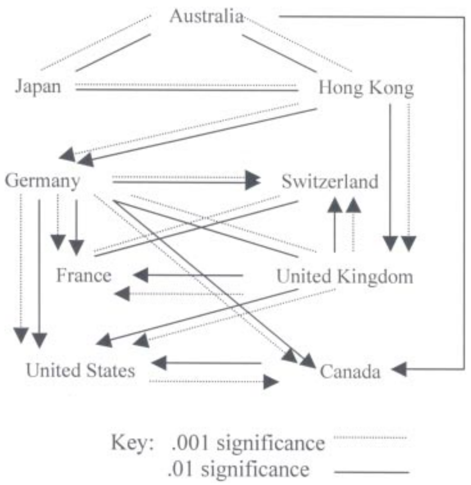
As explained, the DAG analysis begins with a complete undirected graph connecting innovations from every country with every other country in the study. Edges are removed by considering zero-order conditioning (testing of significance on each of the correlations in equation [4]). Edges not statistically different from zero are removed. Significance levels of 0.01 and 0.001 are considered here for edge removal. Although the latter is quite small, our sample size is quite large for DAG analysis (1800 observations). Monte Carlo experiments reported in Spirtes et al. (2000) indicate that one should apply an inverse relation between sample size and significance level. For sample size less than 100 observations, they suggest p-values in the neighborhood of 0.20, their recommendation for 100 to 200 observations is a significance level of 0.10, and so on. By reporting results at both the 0.01 and 0.001 significance levels, we give readers a sense of the robustness of the DAG results. Where the alternative significance levels result in disagreements on edges (one instance) or both yield undirected edges (five instances), we use a version of Schwarz loss (to be explained) to decide on the final model used for analysis.

Edges are removed based on a complete set of conditional and unconditional correlations at the 0.001 and 0.01 significance levels. Given the removed edges, the remaining edges are directed using sepset conditions (already defined) and knowledge of real-time sequences of opening and closing in these markets. Figure 2A gives the pattern from TETRAD II's application to the remaining edges. To illustrate the use of the *sepset* conditions, consider the triple: (Hong Kong–Germany–U.S.). The edge between Hong Kong and the United States is removed by conditioning on Germany. So Germany is in the subset of Hong Kong and the United States. Thus we cannot direct the edges as: Hong Kong → Germany ← U.S. On the other hand, because the Hong Kong market closes early in the day relative to Germany, we forbid (the close in) Germany to cause (the close in) Hong Kong, so TETRAD II directs this edge as Hong Kong → Germany. Given this edge and the knowledge from the sepset argument, we direct the edge between Germany and the United States as Germany → U.S.

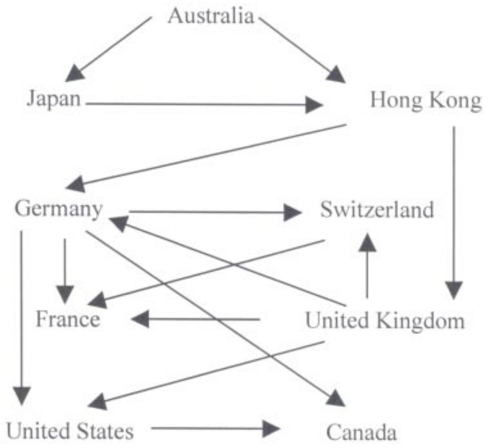
---

[7] We use observed residuals (innovations) from a first-stage VAR model as input in the directed graph algorithm. A reviewer has correctly pointed out that TETRAD is designed to deal with correlations based on actual data and that we do not know the asymptotic distribution of our test statistic when we use observed rather than "true" innovations. A caveat is that we assume that observed residuals are consistently estimated and the test statistics remain valid. This is an important area for future research.

FIGURE 2
The Pattern (**A**) and Directed Graph (**B**) on Innovations from Nine Stock Index Futures Markets



A: Pattern from TETRAD II



B: DAG from *SL and TETRAD II**

Note: **A** (the pattern) is generated under the restriction that innovations in the Asia-Pacific markets cannot be caused by innovations in the European or North American markets. All edges are significantly different from zero at either the 0.001 level (dotted lines) or the 0.01 level (solid lines). **B** is derived by taking **A** as a starting point and uses a modified Schwarz loss metric (*SL**) to score all possible DAGs by directing undirected edges and/or conflicting edges found at varying significance levels with TETRAD II.

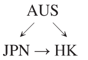
A similar argument is used to direct the Hong Kong → Germany → France path. The edge between Hong Kong and France is removed by conditioning on Germany (Germany and the United Kingdom at the 0.01 level). So Germany is in the sepset of Hong Kong and France. We know that Germany is not a collider between Hong Kong and France; but because Hong Kong causes Germany, it must be the case that France is the end variable in the chain Hong Kong → Germany → France. Other edges are directed using similar arguments as those offered here.

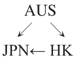
The difference between the results at 0.001 and 0.01 is that the edge between Australia and Canada is present at the higher level of significance. This introduces a discrepancy in the directed edge between the United States and Canada. At the 0.01 level, the edge between the United States and Australia is removed by conditioning on Australia (p-value of 0.0885). Accordingly, Canada is in the sepset of United States and Australia, so we cannot direct the edge U.S. → Canada at the 0.01 level. The edge between Canada and Australia is removed at the 0.001 level by conditioning on the United States and Germany; the sepset argument is not invoked at the 0.001 level. (We will resolve this discrepancy using statistical loss functions.)

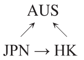
The final pattern is given in Figure 2A. Edges between Australia, Japan, and Hong Kong are found, but the issue of direction of causal flow among the three Asian-Pacific markets could not be sorted out because no edge is removed and there are no disjoint trading times among the three markets. Nevertheless, the Hong Kong market communicates with the markets in Germany and the United Kingdom (at both significance levels), and the Australian market communicates its information to the market in Canada at the 1% level of significance. Within Europe, innovations in the German and UK markets move the French and Swiss markets. TETRAD II is not able to direct the Switzerland–France and the UK–Germany edges. Two European markets (Germany and United Kingdom) move (cause) the U.S. market in contemporaneous time. Innovations in the German market also cause innovations in Canada. Finally, TETRAD II offers conflicting edge direction between the U.S. and Canadian markets, depending on levels of significance.

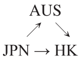
To shed further light on the direction of the U.S.–Canada edge and the edges that TETRAD II does not direct—UK–GER, FRN–SWISS, AUS–JPN, AUS–HK, and HK–JPN—we consider scoring alternative DAGs using a version of Schwarz loss metric.

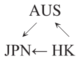
Following Haigh and Bessler (forthcoming), we score each of the 96 alternative DAGs that are consistent with the edges in Figure 2A. We have six alternative DAGs that are consistent with the three undirected edges in the Asian/Pacific markets:

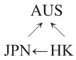




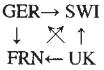


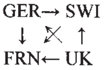


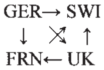


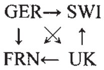


For each of these six Asian/Pacific DAGs we have four alternative DAGs to score on European markets (undirected flows between Germany and United Kingdom and Switzerland and France):









Further, for the 24 models (6 × 4) we consider two DAGs reflecting the ambiguity in North American markets: U.S. ← CAN and U.S. ← CAN. Finally, for each of these 48 DAGs (6 × 4 × 2) we consider two alternative models for the Australian–Canada edge (Australia causes Canada and Australia and Canada are independent in contemporaneous time, given knowledge of activity in the other seven markets): AUS → CAN and AUS (no edge) CAN.

Each of the 96 alternative graphs is consistent with the pattern presented in Figure 2A (at either the 0.01 or 0.001 levels of significance or the undirected edges associated with Asian-Pacific and European country indices). We use seemingly unrelated regressions (similar results are obtained using ordinary least squares) to fit a structural equation model on the innovations from the ECM for each of the 96 alternative DAGs. We apply a modified Schwarz-loss metric to each of the 96 graphs: $SL^* = \log(\text{Trace}[\Sigma]) + k\log(T)/T$. Here Σ represents the variance-covariance matrix associated with a linear representation of the disturbance terms from an acyclic graph fit to innovations from the ECM, k represents the number of coefficients fit on each graph, and T is the number of observations used to fit the graphs (1804). The DAG offered in Figure 2B results in the lowest modified Schwarz-loss metric.[8]

In terms of the Asian-Pacific countries, the DAG shows causal flow from Australia to both of the other Asian markets and from Japan to Hong Kong. Further more, the flow in Europe is found as United Kingdom causes Germany and Switzerland causes France. In addition, the modified SL metric supports the causal flow of information from the U.S. market to the Canadian market. Finally, the modified SL metric supports no edge between Australia and Canada. The final model is a DAG as represented in Figure 2B. It is interesting to note that the instantaneous price transmission pattern in this study is not identical to the pattern on stock cash indexes on the same nine markets as studied in Bessler and Yang (2003) (see figure 2 in their study). The dissimilarity may be (at least) partly due to the fact that equity index futures prices instead of the cash market indexes are used.

The DAG given in Figure 2B gives us the following representation on innovations in contemporaneous time is given in matrix equation (5):

$$(5)\quad \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ a_{21} & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ a_{31} & a_{32} & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & a_{43} & 1 & 0 & a_{46} & 0 & 0 & 0 \\ 0 & 0 & 0 & a_{54} & 1 & a_{56} & a_{57} & 0 & 0 \\ 0 & 0 & a_{63} & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & a_{74} & 0 & a_{76} & 1 & 0 & 0 \\ 0 & 0 & 0 & a_{84} & 0 & a_{86} & 0 & 1 & 0 \\ 0 & 0 & 0 & a_{94} & 0 & 0 & 0 & a_{98} & 1 \end{bmatrix} \times \begin{bmatrix} v_{AUS,t} \\ v_{JPN,t} \\ v_{HK,t} \\ v_{GER,t} \\ v_{FRN,t} \\ v_{UK,t} \\ v_{SWI,t} \\ v_{US,t} \\ v_{CAN,t} \end{bmatrix} = \begin{bmatrix} e_{AUS,t} \\ e_{JPN,t} \\ e_{HK,t} \\ e_{GER,t} \\ e_{FRN,t} \\ e_{UK,t} \\ e_{SWI,t} \\ e_{US,t} \\ e_{CAN,t} \end{bmatrix}$$

Here the $v_{country,\ t}$ terms are observed innovations from the ECM and the $e_{country,\ t}$ are orthogonal innovations from each country.

Based on a model of innovations in contemporaneous time that follows equation (5) and

---

[8] Detailed results on the modified Schwarz loss metric are available on request. A general statement that holds throughout the search is the DAGs that include the Australia→Canada edge have larger SL^* metrics than those not having this edge, all other edges the same.

TABLE 1
Forecast Error Variance Decompositions from an ECM with Contemporaneous Structure as Modeled in Figure 2B

Step	AUS	JPN	HK	GER	SWL	FRN	UK	US	CAN
(AUS)									
0	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	82.06	0.01	0.80	0.69	0.01	0.05	6.47	9.77	0.14
2	77.83	0.01	0.98	0.92	0.02	0.07	7.91	12.12	0.14
30	51.82	0.14	9.34	1.61	3.48	1.26	12.01	20.19	0.16
(JPN)									
0	5.39	94.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	4.48	88.44	0.41	0.25	0.16	0.16	3.64	2.46	0.00
2	4.23	86.96	0.42	0.33	0.16	0.17	4.42	3.30	0.00
30	4.23	83.21	0.53	0.38	0.09	0.18	7.14	4.25	0.00
(HK)									
0	12.13	2.59	85.29	0.00	0.00	0.00	0.00	0.00	0.00
1	9.63	1.84	77.49	0.07	0.15	0.00	4.39	6.30	0.13
2	9.47	1.68	76.17	0.11	0.15	0.00	4.67	7.63	0.12
30	17.09	1.31	63.40	0.96	0.21	0.02	1.38	15.57	0. 07
(GER)									
0	0.92	0.20	6.47	52.50	0.00	0.00	39.91	0.00	0.00
1	0.49	0.10	6.63	48.72	0.02	0.00	40.34	3.68	0.03
2	0.35	0.06	6.70	48.73	0.02	0.00	40.32	3.79	0.02
30	2.31	0.01	10.51	46.99	0.35	0.09	36.31	3.41	0.01
(SWL)									
0	0.57	0.12	4.03	14.99	46.88	0.00	33.39	0.00	0.00
1	0.33	0.13	3.77	14.55	43.60	0.00	34.70	2.91	0.00
2	0.26	0.12	3.62	14.80	43.48	0.00	34.61	3.09	0.00
30	0.28	0.14	3.94	15.78	48.41	0.02	27.70	3.71	0.02
(FRN)									
0	0.68	0.15	4.82	17.09	0.65	36.15	40.45	0.00	0.00
1	0.41	0.07	4.82	17.70	0.40	31.15	40.93	4.48	0.04
2	0.31	0.05	4.80	18.32	0.34	30.53	40.82	4.79	0.03
30	1.06	0.01	6.49	20.27	1.26	32.20	33.04	5.65	0.01
(UK)									
0	0.96	0.20	6.72	0.00	0.00	0.00	92.11	0.00	0.00
1	0.51	0.09	6.22	0.00	0.01	0.00	88.13	4.99	0.02
2	0.39	0.07	6.06	0.01	0.01	0.00	88.05	5.39	0.02
30	0.68	0.05	6.58	0.86	1.42	0.08	75.82	14.46	0.03
(US)									
0	0.24	0.05	1.69	2.99	0.00	0.00	16.59	78.43	0.00
1	0.14	0.05	1.57	3.61	0.01	0.00	18.29	76.33	0.01
2	0.09	0.05	1.62	3.75	0.01	0.00	18.71	75.75	0.01
30	1.69	0.04	3.91	3.28	0.09	0.09	22.43	68.46	0.01
(CAN)									
0	0.87	0.03	1.01	3.16	0.00	0.00	8.72	23.42	62.79
1	0.59	0.02	1.12	3.86	0.06	0.04	10.03	27.16	57.12
2	0.47	0.02	1.18	4.09	0.07	0.06	10.42	27.73	55.97
30	0.66	0.01	3.00	3.75	0.40	0.18	13.24	25.81	52.94

Notes: Decompositions at each step are given for a structural factorization of the innovation correlation/covariance matrix as suggested in Bernanke (1986) and Sims (1986). The percentages sum to 100 in each row. The order of presentation and abbreviations for each country is as follows: Australia (AUS), Japan (JPN), Hong Kong (HK), Germany (GER), Switzerland (SWL), France (FRN), the United Kingdom (UK), the United States (US), and Canada (CAN).

a structural factorization as suggested in Bernanke (1986) and Sims (1986), the forecast error variance decompositions are conducted and given in Table 1. Table entries give the percentage of price variation in each market positioned at time $t+k$ that is due to innovations in each other market (including itself) at time t. Listed here are the results at horizons of 0 (contemporaneous time), 1 and 2 days (short horizon), and 30 days ahead (longer horizon).

Australia is highly exogenous at the short horizon but much less so at the longer horizon. At 30 days ahead, the United States (20%), United Kingdom (12%), and Hong Kong (9%) together account for 41% of the variation in the Australian market. The variation in the Japanese market is not well explained by innovations from other markets, either at the short or longer horizon, perhaps with the exception of the United Kingdom (7%) at the 30-day horizon. The Hong Kong market is also explained predominantly by earlier innovations in the Hong Kong and Australian markets at the short horizon. At the 30-day horizon, Australia (17%), the United States (16%), and Hong Kong itself (63%) account for the preponderance of the variation in the Hong Kong market.

The German market appears to be substantially explained by the variation in the United Kingdom (36%–40%) at all horizons. The primary influences on the Swiss market are variations in itself (43%–48%), the UK market (28%–35%), and the German market (15%). The UK and German markets explain about 33%–41% and 17%–20%, respectively, of the variation in the French market at all horizons. The UK market is among the most exogenous markets, exceeded only by Japan in terms of percentage of variation due to its own shock at longer horizon (76% for UK compared to 83% for Japan at the 30-day horizon). Only the United States can exert a noticeable impact on the United Kingdom at the longer 30-day horizon (14%).

The U.S. market is also quite exogenous at all horizons as its price variation is explained primarily by itself (68%–78%) at all horizons. However, innovations in the UK market consistently have a substantial influence on the U.S. market (16%–22%). Finally, innovations in the U.S. market account for about 25% of the variation in the Canadian market at all horizons. At the 30-day horizon, a nontrivial contribution from the UK market (about 13%) is also observed.

For the purpose of comparison, forecast error variance decompositions are also given using the Choleski decomposition using the ordering given in Eun and Shim (1989): US, UK, SWL, JPN, HK, GER, FRN, CAN, AUS. Eun and Shim (1989, 247) argue that any ordering that puts the United States at the top would suffice to determine the exogeneity of U.S. stock market returns. Many studies on international stock market relationships, such as Lee and Jeon (1995), follow such ordering of placing the United States on the top in the Choleski decomposition. The results of this ordering are shown in Table 2. Although results on some markets (e.g., Japan) are little changed, results in Table 2 are quite different from those in Table 1, which substantiate the argument recently made by Swanson and Granger (1997). Some noticeable differences are discussed as follows.

First, by placing the United States on the top of the ordering in the Choleski decomposition, the influence of the U.S. market on the other countries is two or more times larger than the influence found employing the DAG-based structural decomposition (i.e., the structural factorization based on the directed graph). For example, at 30 days ahead, the DAG-based structural decomposition (Table 1) attributes the following percentages to innovations in the U.S. market: 20.19% Australia; 4.25% Japan; 15.57% Hong Kong; 3.41% Germany; 3.71% Switzerland; 5.65% France; 14.46% UK; and 25.81% Canada. By contrast, under the Choleski decomposition, the percentages attributed to U.S. innovations are: 42.83% Australia; 13.47% Japan; 27.03% Hong Kong; 31.43% Germany; 25.49% Switzerland; 33.37% France; 53.31% UK; and 42.07% Canada. Clearly, the Choleski decomposition suggested by Eun and Shim (1989) results in a much larger role for the U.S. market. As the DAG-based structural decomposition indicates, the United States does not have a substantial influence on several of the European markets (save perhaps the United Kingdom at 30 days) or Japan. That the U.S. influence on other markets may be seriously overestimated by placing the United States first in a Choleski decomposition is an important finding that has been ignored in several previous studies.

Second, the exogeneity of the U.S. market is also seriously affected by the Choleski

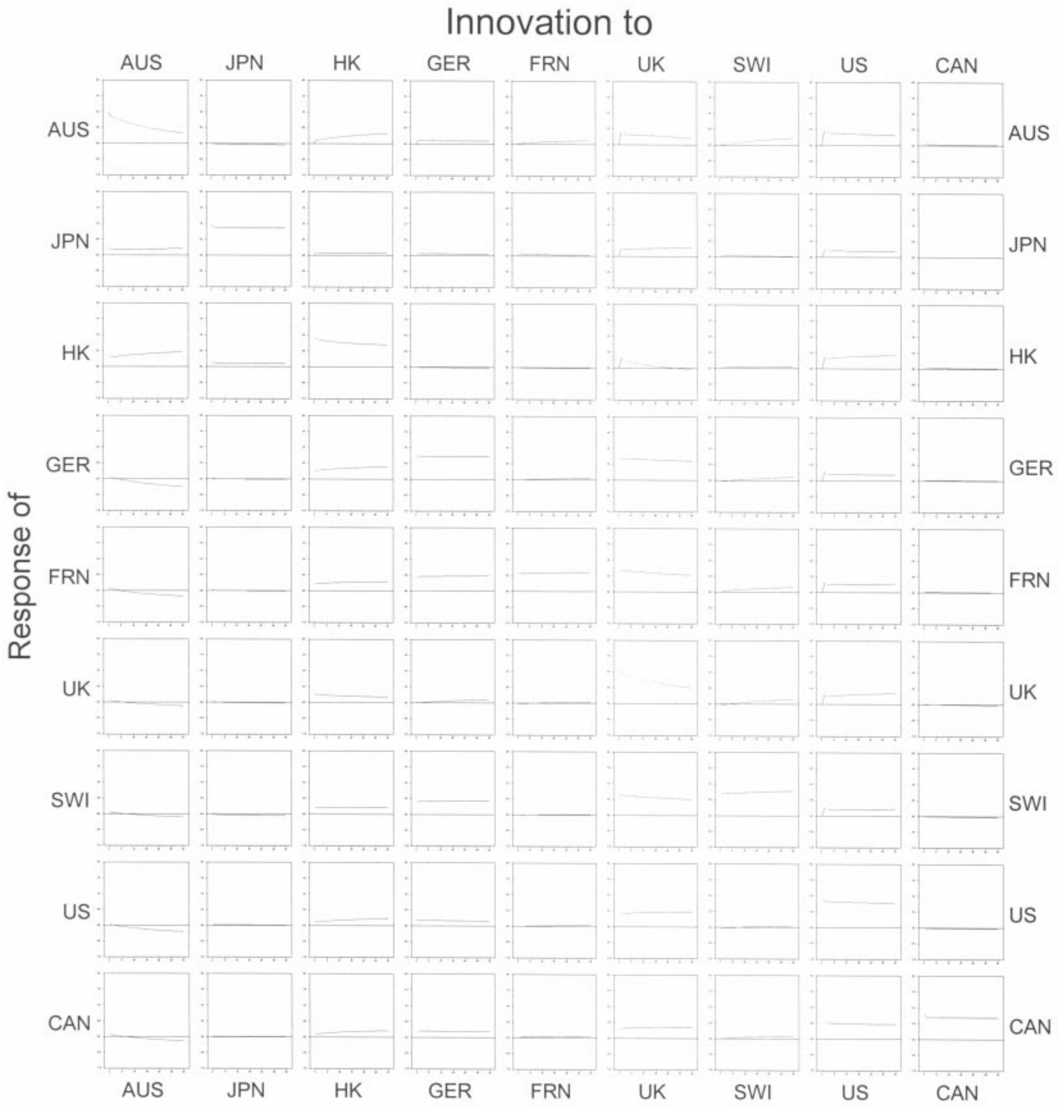
TABLE 2
Forecast Error Variance Decompositions from an ECM with Contemporaneous Structure as Modeled Using a Choleski Factorization

Step	**AUS**	**JPN**	**HK**	**GER**	**SWL**	**FRN**	**UK**	**US**	**CAN**
(AUS)									
0	84.19	4.03	7.34	0.00	0.67	0.03	2.16	1.33	0.24
1	63.70	2.69	5.99	0.02	0.71	0.03	4.27	22.09	0.51
2	59.00	2.32	5.69	0.03	0.75	0.04	4.70	26.96	0.52
30	32.61	0.84	11.44	0.39	4.66	1.03	5.75	42.83	0.45
(JPN)									
0	0.00	96.86	0.00	0.00	0.18	0.00	2.45	0.50	0.00
1	0.14	86.08	0.00	0.00	0.53	0.16	5.26	7.82	0.00
2	0.16	83.42	0.01	0.00	0.57	0.17	5.75	9.92	0.00
30	0.11	77.45	0.02	0.00	0.47	0.17	8.29	13.47	0.00
(HK)									
0	0.00	3.62	88.28	0.00	0.21	0.00	6.21	1.68	0.00
1	0.06	2.37	72.28	0.16	0.32	0.00	8.26	16.44	0.12
2	0.04	2.12	69.60	0.16	0.34	0.00	8.19	19.43	0.11
30	1.60	2.47	65.38	0.04	0.91	0.02	2.45	27.03	0.10
(GER)									
0	0.00	0.05	0.43	38.91	11.87	0.00	30.96	17.76	0.00
1	0.11	0.11	0.37	34.29	9.64	0.00	25.08	30.36	0.02
2	0.19	0.12	0.34	34.13	9.31	0.00	24.01	31.88	0.02
30	5.55	0.61	0.64	30.29	11.72	0.12	19.62	31.43	0.02
(SWL)									
0	0.00	0.00	0.00	0.00	60.82	0.00	25.73	13.45	0.00
1	0.01	0.35	0.03	0.03	55.01	0.00	20.93	23.62	0.00
2	0.02	0.40	0.05	0.04	54.74	0.00	19.80	24.96	0.01
30	0.86	0.82	0.03	0.08	59.71	0.02	12.95	25.49	0.04
(FRN)									
0	0.00	0.12	0.21	9.53	6.83	35.92	31.25	16.23	0.00
1	0.04	0.07	0.15	8.88	5.38	30.89	24.39	30.16	0.03
2	0.08	0.05	0.13	9.15	5.17	30.30	22.96	32.14	0.03
30	2.71	0.18	0.23	8.43	7.33	32.79	14.95	33.37	0.01
(UK)									
0	0.00	0.00	0.00	0.00	0.00	0.00	81.46	18.53	0.00
1	0.09	0.18	0.03	0.08	0.09	0.00	66.22	33.29	0.02
2	0.12	0.20	0.05	0.07	0.09	0.00	63.80	35.65	0.01
30	1.82	0.79	0.07	0.16	1.11	0.09	42.58	53.31	0.05
(US)									
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00
1	0.03	0.00	0.04	0.08	0.00	0.00	0.06	99.77	0.01
2	0.08	0.01	0.04	0.09	0.00	0.00	0.07	99.69	0.01
30	3.36	0.20	0.01	0.03	0.04	0.11	0.52	95.71	0.03
(CAN)									
0	0.00	0.13	0.07	0.22	0.20	0.08	0.96	35.98	62.37
1	0.06	0.08	0.04	0.24	0.41	0.18	0.91	41.49	56.59
2	0.10	0.07	0.03	0.26	0.47	0.21	0.93	42.54	55.40
30	2.72	0.03	0.10	0.10	0.81	0.49	1.79	42.07	51.88

Notes: Decompositions at each step are given for a Choleski factorization of the innovation correlation/covariance matrix. The ordering of variables in the Choleski factorization is as follows: US, UK, SWI, JPN, HK,GER, FRN, CAN, and AUS. The decompositions sum to 100 in any row. The order of presentation and abbreviations for each country is as follows: Australia (AUS), Japan (JPN), Hong Kong (HK), Germany (GER), Switzerland (SWL), France (FRN), the United Kingdom (UK), the United States (US), and Canada (CAN). The ordering is given as in Eun and Shim (1989): US, UK, SWL, JPN, HK, GER, FRN, CAN, AUS.

FIGURE 3

Impulse Response to One-Time-Only Shocks in Each Series Based on a Structural Factorization Following Figure 2B



decomposition. In Table 1, at the 30-day horizon, the United States accounts for about 68% of its own variation, leaving about 32% of its variation due to non-U.S. influences. By placing the United States first in the Choleski factorization, we show it to be nearly exogenous, because over 95% of its variation is explained by its own historical variation at all horizons. Furthermore, the Choleski decomposition shows the United Kingdom to be much less exogenous, relative to the decompositions based on the DAG. Much of the influence in the UK market attributed to itself in Table 1 is passed through to the United States in Table 2. In Table 1 (DAG-based decompositions) at the 30-day horizon the United Kingdom explains about 76% of its own variation and the United States explains about 14% of the UK variation. In the Choleski decomposition, the United Kingdom accounts for only 42% of its variation at the 30-day horizon and the United States accounts for 53%.

Finally, under the ordering of innovations as generated by the directed graph (Figure 2B), the impulse responses are plotted in Figure 3. These responses, which may serve as a robustness check, are generally consistent with the results from forecast error variance decompositions. Specifically, Australia responds noticeably to shocks from the United States, the United Kingdom, and Hong Kong. Japan shows little response to shocks from other markets, although some appreciable responses to shocks in the United States and United Kingdom are present. Hong Kong responds positively to shocks in Australia, the United Kingdom, and the United States. Germany responds very strongly to the shock from the United Kingdom. France responds strongly to the shocks from Germany, the United Kingdom, and the United States. The United Kingdom responds noticeably to shocks in the United States and mildly to Hong Kong. Switzerland shows its most significant response to shocks in the United Kingdom and Germany. The U.S. market only shows significant responses to shocks from the United Kingdom. Canada responds significantly to shocks from the United States and also noticeably to the United Kingdom. Both the impulse response analysis and forecast error variance decomposition results confirm that the United States and the United Kingdom influence price variations in most markets. Japan, France, and Canada have little dynamic effect on other markets.

V. CONCLUSIONS

This study investigates price transmission patterns in the nine stock index futures markets, applying an empirical framework that combines cointegration, ECM, innovation accounting, and DAG methods in a relatively novel way. Different from recent studies on international equity markets such as those seen in Francis and Leachman (1998), Masih and Masih (2001), and Bessler and Yang (2003), where only one cointegrating vector is found among major stock markets, stock index futures prices from the nine major markets are cointegrated with two cointegrating vectors. The instantaneous transmission pattern of these market innovations is further explored, using the DAG technique to help sort out causal ordering in contemporaneous time. The instantaneous transmission pattern only to some extent resembles the pattern found on international stock markets in the earlier paper of Bessler and Yang (2003).

The identified instantaneous causal structure is crucial in further data-determined innovation accounting analysis. The short-run dynamic pattern of price transmission reveals that the Japanese and UK markets are most highly exogenous among the nine markets in the sense that price information from other major stock markets explains a relatively small proportion of price movements in these markets even at a longer horizon. Furthermore, innovations from the Japanese market explain relatively little of the stock price movement in other markets. In this sense, the Japanese market is highly isolated from all other stock index futures markets, which is consistent with findings in Arshanapalli and Doukas (1993) and Bessler and Yang (2003) on international stock markets. However, it contradicts the argument that Japan is a leader in world equity markets as discussed in Koch and Koch (1991) and Masih and Masih (2001). Consistent with Bessler and Yang (2003), the French and Canadian markets are found to be the least exogeneous of the nine markets in the sense that information from other stock index futures markets is prevalent in explaining the stock price movements in these markets. The finding is also consistent with Eun and Shim (1989) regarding the Canadian market being highly endogenous.

The predominant role of the U.S. market in the world stock market has been much emphasized in the literature by Eun and Shim (1989), Hamao et al. (1990), and Arshanapalli and Doukas (1993). Eun and Shim (1989) report that the U.S. market is the most exogenous market. This argument is not fully supported in our study, although the US market is still among the more highly exogenous markets. The evidence of the U.S. market's role as the leader in stock index futures markets is also weaker than what has been reported in the literature. In particular, the U.S. market appears to exert a noticeable impact on most Asian and North American markets but not on most European markets. Instead, the UK and German markets are found to exert significant influences on the European markets. The emergence of such leadership in Europe, rather than following the United States, may be a reflection of more integrated European economies due to accelerated regional economic integration processes since the early 1990s. At the Maastricht summit in 1991, the European Monetary System's member countries signed an agreement outlining the requirements and a timetable for moving to a European Monetary Union. To our knowledge, such a strong regional integration pattern in the major European equity markets has not been reported in the literature.

The leadership of the United Kingdom and Germany in Europe may not be surprising, given the facts that Germany is the most important economy in Europe and the UK stock market is the largest in Europe (and only behind the United States and Japan in the world). In addition, London is one of the three largest financial centers in the world (i.e., New York, London, and Tokyo) and considered the most internationalized in its outlook as argued by Masih and Masih (2000, 578). In fact, the leadership role of the United Kingdom appears to be comparable to the United States in the international stock index futures markets, and the influence of the United Kingdom is also present in some Asian markets and both North American markets. Overall, the result clearly suggests that the United Kingdom shares the leadership role with the United States in international stock index futures markets, which is consistent with Masih and Masih (2001) and not documented in many previous studies, including Eun and Shim (1989), Koch and Koch (1991), and Bessler and Yang (2003).

Finally, although several factors (such as different sample periods) could partly account for the discrepancy between our results and those from earlier studies, this study challenges the earlier work of Von Furstenberg and Jeon (1989) and Eun and Shim (1989) by demonstrating that innovation accounting analysis based on the Choleski decomposition, with the United States placed at or near the top, can be seriously misleading. The finding also exemplifies the empirical implications of data-determined contemporaneous structural modeling, as projected in Swanson and Granger (1997).

REFERENCES

Agmon, T. "The Relations among Equity Markets: A Study of Share Price Co-movements in the United States, United Kingdom, Germany, and Japan." *Journal of Finance*, 27, 1972, 839–55.

Arshanapalli, B., and J. Doukas. "International Stock Market Linkages: Evidence from the Pre- and Post-October 1987 Period." *Journal of Banking and Finance*, 17, 1993, 193–208.

Battley, N. *The World's Futures & Options Markets*, 2nd edn. New York: Wiley, 2000.

Bernanke, B. "Alternative Explanations of the Money-Income Correlation." *Carnegie-Rochester Conference Series on Public Policy*, 25, 1986, 49–99.

Bessler, D. A., and J. Yang. "The Structure of Interdependence in International Stock Markets." *Journal of International Money and Finance*, 22, 2003, 261–87.

Bessler, D. A., J. Yang, and M. Wongcharupan. "Price Dynamics in the International Wheat Market: Modeling with Error Correction and Directed Graphs." *Journal of Regional Science*, 43, 2003, 1–33.

Eun, C., and S. Shim. "International Transmission of Stock Market Movements." *Journal of Financial and Quantitative Analysis*, 24, 1989, 241–256.

Francis, B., and L. Leachman. "Superexogeneity and the Dynamic Linkages among International Equity Markets." *Journal of International Money and Finance*, 17, 1998, 475–92.

Gonzalo, J. "Five Alternative Methods of Estimating Long-Run Equilibrium Relationships." *Journal of Econometrics*, 60, 1994, 203–33.

Haigh, M., and D. A. Bessler. "Causality and Price Discovery: An Application of Directed Acyclic Graphs." *Journal of Business*, forthcoming.

Hakkio, C. S., and M. Rush. "Cointegration: How Short Is the Long Run?" *Journal of International Money and Finance*, 10, 1991, 571–81.

Hamao, Y., R. Masulis, and V. Ng. "Correlation Price Changes and Volatility across International Stock Markets." *Review of Financial Studies*, 3, 1990, 281–307.

Hasbrouck, J. "One Security, Many Markets: Determining the Contributions to Price Discovery." *Journal of Finance*, 50, 1995, 1175–99.

Johansen, S. "Estimation and Hypothesis Testing of Cointegration vectors in Gaussian Vector Autoregressive Models." *Econometrica*, 59, 1991, 1551–80.

Johansen, S., and K. Juselius. "Identification of the Long-Run and the Short-Run Structure: An Application to the ISLM Model." *Journal of Econometrics*, 63, 1994, 7–36.

Kawaller, I., P. Koch, and T. Koch. "The Temporal Price Relationship between S&P 500 Futures and the S&P 500 Index." *Journal of Finance*, 42, 1987, 1309–29.

Koch, P., and T. Koch. "Evolution in Dynamic Linkages across Daily National Stock Indexes." *Journal of International Money and Finance*, 10, 1991, 231–51.

Lee, B. S., and B. N. Jeon. "Common Stochastic Trends and Predictability of International Stock Prices." *Journal of the Japanese and International Economies*, 9, 1995, 245–77.

Lin, W., R. F. Engle, and T. Ito. " Do Bulls and Bears Move across Boarders? International Transmission of Stock Returns and Volatility." *Review of Financial Studies*, 7, 1994, 507–38.

Lutkepohl, H., and H. Reimers. "Impulse Response Analysis of Cointegrated Systems." *Journal of Economic Dynamics and Control*, 16, 1992, 53–78.

Malliaris, A., and J. Urrutia. "The International Crash of October 1987: Causality Tests." *Journal of Financial and Quantitative Analysis*, 27, 1992, 353–64.

Masih, R., and A. M. M. Masih. "Long and Short Term Dynamic Causal Transmission amongst International Stock Markets." *Journal of International Money and Finance*, 20, 2001, 563–87.

Pearl, J. "Causal Diagrams for Empirical Research." *Biometrika*, 82, 1995, 669–710.

———. *Causality*. Cambridge: Cambridge University Press, 2000.

Phillips, P. "Impulse Response and Forecast Error Variance Asymptotics in Nonstationary VARs." *Journal of Econometrics*, 83, 1998, 21–56.

Scheines, R., P. Spirtes, C. Glymour, and C. Meek. *TETRAD II: User's Manual and Software*. New Jersey: Lawrence Erlbaum Associates, 1994.

Sims, C. "Macroeconomics and Reality." *Econometrica*, 48, 1980, 1–48.

———. "Forecasting Models for Policy Analysis." *Quarterly Review of Federal Reserve Bank of Minneapolis*, 10, 1986, 2–16.

Spirtes, P., C. Glymour, and R. Scheines. *Causation, Prediction, and Search*. Cambridge: MIT Press, 2000.

Swanson, N., and C. W. J. Granger. "Impulse Response Functions Based on a Causal Approach to Residual Orthogonalization in Vector Autoregression." *Journal of the American Statistical Association*, 92, 1997, 357–67.

Taylor, M., and I. Tonks. "The Internationalization of Stock Markets and the Abolition of U.K. Exchange Control." *Review of Economics and Statistics*, 71, 1989, 332–36.

Toda, H. Y., and P. C. B. Phillips. "Vector Autoregressions and Causality." *Econometrica*, 61, 1993, 1367–93.

Von Furstenberg, G. M., and B. N. Jeon. "International Stock Price Movements: Links and Messages." *Brookings Papers on Economic Activity*, 1, 1989, 125–79.

Yang, J. "Market Segmentation and Information Asymmetry in Chinese Stock Markets: A VAR Analysis." *Financial Review*, 38, 2003, 591–609.