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Testing causal relationships between wholesale electricity prices and primary energy prices

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HIGHLIGHTS

- We test the Granger-causality among wholesale electricity and primary energy prices.
- We test not only the causality in mean but also the causality in variance.
- The results show that gas prices Granger-cause electricity prices in mean.
- We find no Granger-causality in variance among these variables.

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ABSTRACT

We apply the lag-augmented vector autoregression technique to test the Granger-causal relationships among wholesale electricity prices, natural gas prices, and crude oil prices. In addition, by adopting a cross-correlation function approach, we test not only the causality in mean but also the causality in variance between the variables. The results of tests using both techniques show that gas prices Granger-cause electricity prices in mean. We find no Granger-causality in variance among these variables.

1. Introduction

In the past, it was considered natural that competition was restricted and companies operated monopolistically in the electricity industry. Around 1990, however, the industry began to be liberalized, as many countries deregulated their electricity industries. The wholesale electricity industries in most states of the United States are now open to competition among players in the market. Market structures differ by geographical area, with negotiated- and organized-transaction markets being the two main market types. In a negotiated-transaction market, electricity transactions are directly negotiated by sellers and buyers, and individual transmission line owners establish their own electricity supply plans. On the other hand, in an organized-transaction market, an entity independent of market participants controls all transmission facilities and operates a spot market, with a few exceptions.

In December 1999, the United States Federal Energy Regulatory Commission (FERC) issued Order No. 2000 regarding the formation of Regional Transmission Organizations (RTOs). This order asked all the electric utilities owning and operating a transmission system to participate in establishing an organization to operate the system over a large area and in a neutral manner. Entergy TransCo is one such RTO established on the basis of Order No. 2000. This type of RTO is a regulated, for-profit stock company that either owns or leases under long-term contracts all the transmission facilities within a specified area. It is the administrator and operator of the transmission system, responsible for investing in new transmission facilities. The Entergy wholesale market prices are determined at the regional trading hub.

An empirical analysis of the relationship between wholesale electricity as a secondary energy source and crude oil, natural gas, coal, and uranium as primary energy sources would contribute greatly to the national energy policy and to the business and trading strategies of those in the energy business. Questions concerning the long-term relationship between the prices of primary energy sources and electricity—such as whether changes in international crude oil prices are useful in predicting regional wholesale electricity price movements or whether there is a volatility spillover effect between the wholesale electricity and

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Table 1
Causality tests of the relationships between electricity prices and primary energy prices in the United States.

Sources	Study period	Variables electricity	Natural gas/Oil	Causality tests between electricity prices and others	Summary
Brown and Yücel (2008)	1997–2007	PJM, PV	Henry Hub, TZ6, Topock	TZ6→PJM Topock→PV	There is bidirectional causality between regional gas and electricity prices, but no causality between gas wellhead and regional electricity prices.
Woo et al. (2006)	1999–2004	NP15, SP15 (CAISO)	PG&E Citygate, SoCal	PG&E Citygate→NP15 SoCal→NP15 PG&E Citygate→SP15 SoCal→SP15	There is bidirectional causality between gas and electricity prices.
Emery and Liu (2002)	1996–2000	COB, PV	Henry Hub	Henry Hub→COB Henry Hub→PV	Electricity prices respond to departure from the equilibrium relationship, but gas prices do not.
Serletis and Herbert (1999)	1996–1997	PJM	Henry Hub, TZ6, Fuel oil for NY harbor	No test among PJM and others	There appear to be effective arbitraging mechanisms for the prices of gas and fuel oil.

Note: "A→B" means that the past values of "A" give information about the future value of "B."
Serletis and Herbert (1999) argued that the electricity price series is I(0) and each of the other price series is I(1). Therefore, they inferred that the strength of the relationship between the power prices and each of the other prices would be spurious.
PJM and PV represent wholesale electricity market prices in the eastern and western United States, respectively.
Henry Hub, TZ6, and Topock represent a national natural gas market price, and natural gas market prices in the eastern and western United States, respectively.
NP15 and SP15 represent wholesale electricity market prices in northern and southern California, respectively.
PG&E Citygate and SoCal represent natural gas market prices in northern and southern California, respectively
COB represents a wholesale electricity market price in northern California and Oregon.
Fuel oil for NY harbor represents a standard reference price for oil in the U.S. Northeast.

primary energy markets—are of considerable interest from the viewpoint of energy security and energy company management.

West Texas Intermediate (WTI) is a light sweet crude oil considered high-quality fuel for power generation. WTI, which is produced in Texas and is delivered at Cushing, Oklahoma, is consumed in the southern states, while the price of WTI is one of the most major benchmarks for the world oil market. Henry Hub is the pricing point for the natural gas in the pipeline system in Louisiana. The price at Henry Hub is seen to be the primary benchmark for the United States gas market. Recently, Henry Hub has started to be seen as the price index for the world natural gas market. Entergy's service territory includes almost all of Louisiana, the southeastern part of Texas, the eastern three-quarters of Arkansas, and the western half of Mississippi. In other words, Entergy supplies electricity in the region that is a productive center and consuming area of oil and gas, whose prices are international and/or national benchmarks. This region has an extremely rare combination of features.

This creates motivation to examine the southern energy market. By testing for the causal relationships among Entergy, WTI, and Henry Hub, we are able to confirm whether WTI and Henry Hub have features of the regional energy market as well as the international and/or national market. It is significant to investigate the causal relationship in the variance between the international and regional energy markets, and between primary and secondary energy markets, because of both electric power suppliers' and electric power consumers' concerns. Power suppliers desire to discuss the combination of various power sources, ideal fuel contracts, and the best oil stockpile in order to stabilize the cost of power procurement. Power consumers are interested in the selection and combination of energy sources of their facilities, equipment, and appliances in order to stabilize the total cost of energy procurement when they operate and make investments in these items.

We apply the lag-augmented vector autoregression (LA-VAR) technique developed by Toda and Yamamoto (1995) to test for Granger-causality. The LA-VAR approach allows us to test for Granger-causality among time series variables in levels without detecting exactly their integration and cointegration properties. In this respect, it is more advantageous to use the LA-VAR approach than the vector error correction model (VECM) approaches. The pretests for a unit root and cointegration in the economic time series and the estimation of the cointegrating vector are required before the causality test based on the VECM, and therefore the procedure is very complicated.

Moreover, we adopt the cross-correlation function (CCF) approach developed by Cheung and Ng (1996) to test for Granger-causality in volatility as well as level. The traditional tests of causality, developed by Granger (1969) and Engle and Granger (1987), suffer from a number of problems:

- The inability to address anything other than mean relationships.
- Model-building requirements.
- The need to pay attention to the omission of variables.

The CCF approach, in contrast, offers the following advantages. It provides the ability to test for causality not only in the mean but also in the variance, and incorporates the use of univariate model residuals, which makes the building of a multivariate model unnecessary.

Many studies empirically analyzed the Granger-causality between power prices and primary energy prices, because most economists can accept the economic model underlying such a Granger-causal relationship. We introduce some studies from the United States that have empirically analyzed the Granger-causality between power prices and primary energy prices using daily data. We summarize these in Table 1. Although researchers have analyzed the relationship between wholesale electricity prices and primary energy prices in the northeastern and western markets of the United States (for example PJM, PV, CAISO, and COB), no studies have examined the southern market (for example the Entergy Hub), to the best of our knowledge. It is difficult to find general or common causality relationships between electricity prices and the primary energy prices, because not many previous analyses exist. However, Brown and Yücel (2008), Woo et al. (2006), and Emery and Liu (2002) argue that past natural gas prices provide information about future wholesale electricity prices. In addition to these studies, Amavilah (1995) and Mohammadi (2009) tested the