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Volatility and a century of energy markets dynamics☆

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ABSTRACT

How similar is the price behavior of oil, natural gas, and coal? Are there any interactions among these three fuel prices and their volatilities? Using the Yatchew and Dimitropoulos (2016) annual data for the United States, over the period from 1870 to 2014, and state-of-the-art econometric methodology, we explore for spillovers and interactions among the three energy markets. In doing so, we use a range of univariate and multivariate volatility models. The key contribution to the literature is the estimation of a trivariate BEKK model that allows for the interdependence of oil, natural gas, and coal returns and volatilities, using the longest span prices that have ever been studied before.

1. Introduction

In recent years, multivariate volatility models are becoming standard in economics and finance. These models, first proposed by Bollerslev et al. (1988), allow for rich dynamics in the variance–covariance structure of time series, making it possible to model spillovers in both the values and the conditional variances of the series under study. They can be used to investigate a large number of issues in economics and finance. For example, as Bauwens et al. (2006, p. 79) put it, "is the volatility of a market leading the volatility of other markets? Is the volatility of an asset transmitted to another asset directly (through its conditional variance) or indirectly (through its conditional covariances)? Does a shock on a market increase the volatility on another market, and by how much? Is the impact the same for negative and positive shocks of the same amplitude?"

In this paper we estimate univariate and multivariate volatility models for the prices of three hydrocarbons — oil, natural gas, and coal — using the Yatchew and Dimitropoulos (forthcoming) annual data for the United States that span over a century, from 1870 to 2014. The key contribution to the literature is the estimation of a trivariate volatility model that explores the interdependence of oil, natural gas, and coal prices and volatilities, using the longest span data that have ever been studied before. Existing studies have used multivariate volatility models to explore the relationships among several electricity markets (see Worthington et al., 2005), between oil and natural gas markets (see Ewing et al., 2002; Serletis and Shahmoradi, 2006), and between oil markets and financial or macroeconomic indicators (see Lee et al., 1995; Sadorsky, 2012; Elder and Serletis, 2010; Rahman and Serletis, 2012). However, to the best of our knowledge, no study has used multivariate volatility models to model oil, natural gas, and coal prices in a systems context, although there is similar work by Efimova and Serletis (2014) who model crude oil, natural gas, and electricity prices using daily data for the United States over a short period, from 2001 to 2013.

Our research is distinguished from the current literature in a number of ways. The present paper is significantly different from Efimova and Serletis (2014), and even though our research question is similar to Ewing et al. (2002), who discuss the volatility transmission in the oil and natural gas markets, our empirical models have more features. We use a long span, low frequency data set, over the period from 1870 to 2014, and model the returns of oil, natural gas, and coal which are all raw non-renewable energy resources and are the main utilized fuels for energy worldwide. Although temporally aggregated data exhibit smaller GARCH effects than higher frequency data, since the persistence of conditional volatility tends to increase with the sampling frequency, we fit the univariate and multivariate volatility models to the low frequency data. Also, there is no simple method which links

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the presented ARCH and GARCH effects to the estimation results at higher frequencies — see Drost and Nijman (1993), Hafner (2008) and Zivot (2009) for more details regarding these issues.

This paper is also significantly different from Efimova and Serletis (2014). Their work uses daily data (over the period from January 2, 2001 to April 26, 2013) and focuses on two primary forms of energy (oil and natural gas) and an energy carrier (electricity), produced using these two primary energy sources. In this paper we derive univariate forecasting model specifications for three primary energy sources — oil, natural gas, and coal — based on annual time series data. We also model and investigate the spillovers and interactions among the three primary energy sources using the longest span annual price series (from 1870 to 2014) that have ever been studied before. Forecasts of hydrocarbon prices and estimates of the spillovers and interactions among the hydrocarbon markets affect the economic outlook of the country, guiding the development of natural resources and investments in infrastructure. They also play an important role in firm investment and production. Users of hydrocarbon price forecasts and estimates of spillovers and interactions among the hydrocarbon markets include governments, central banks, international organizations, and a range of industries in the broad areas of manufacturing, mining, and utilities.

We focus on the price of crude oil, although oil is not consumed directly but is used as a factor of production in the refining industry (in the production of gasoline, diesel, heating oil, and jet fuel). We are interested in the interaction between the oil market and the coal market, because even before the emergence of a global oil market in the 1970s, there was a well developed market for coal. In fact, coal was the primary fuel in shipping until the 1920s and in railroading and home heating until the 1950s. We are also interested in the interaction between the oil and coal markets and the natural gas market, because natural gas competes with coal in producing electricity and in the manufacturing of chemicals and metals. In 2011, for example, 35.3% of the U.S. energy was generated by oil, while natural gas contributed 24.8%, and coal contributed 19.7%. These fuels exhibit some degree of substitutability and their prices are closely correlated, suggesting that we model interactions among the different markets in a systems context. See Kilian (2015) for more details regarding a historical perspective of the evolution of the oil, coal, and natural gas markets in the United States.

The outline of the paper is as follows. In Section 2 we present the Yatchew and Dimitropoulos (forthcoming) price data on the three hydrocarbons and investigate their time series properties using unit root and stationarity tests. In Section 3 we present two alternative formulations of univariate volatility models for each fuel return and in Section 4 we estimate a trivariate volatility model that explores the interdependence of oil, natural gas, and coal returns and volatilities. The final section briefly concludes the paper.

2. Data and basic facts

We use the Yatchew and Dimitropoulos (forthcoming) annual data on oil and coal for the period from 1870 to 2014 and for natural gas for the period from 1919 to 2014. It is the same data that Yatchew and Dimitropoulos (forthcoming) use and were obtained from Manthy (1978) prior to 1973 and augmented using prices published by the U.S. Energy Information Administration from 1973 to 2014. See Yatchew and Dimitropoulos (forthcoming) for more details regarding the fuel data.

Figs. 1 to 3 plot the natural logs of the oil, natural gas, and coal prices, and their returns, respectively. The oil price is dollars per barrel, the natural gas price is cents per 1000 cubic feet, and the coal price is dollars per ton. Table 1 presents summary statistics for the log levels, $\ln\ o_t$, $\ln\ g_t$, $\ln\ c_t$, and the first differences of the logs, $\Delta\ \ln\ o_t$, $\Delta\ \ln\ g_t$, and $\Delta\ \ln\ c_t$, of the three price series. In general, the p-values for skewness and kurtosis point to significant deviations from symmetry and normality with both the logged series and the first differences of the logs. In fact, the Jarque and Bera (1980) test statistic, distributed as a $\chi^2(2)$ under the null hypothesis of normality, rejects the null hypothesis.

One interesting feature of the data is the contemporaneous correlation between the different prices series. These correlations are reported in Table 2 for log levels (in panel A) and for first differences of log levels (in panel B). To determine whether these correlations are statistically

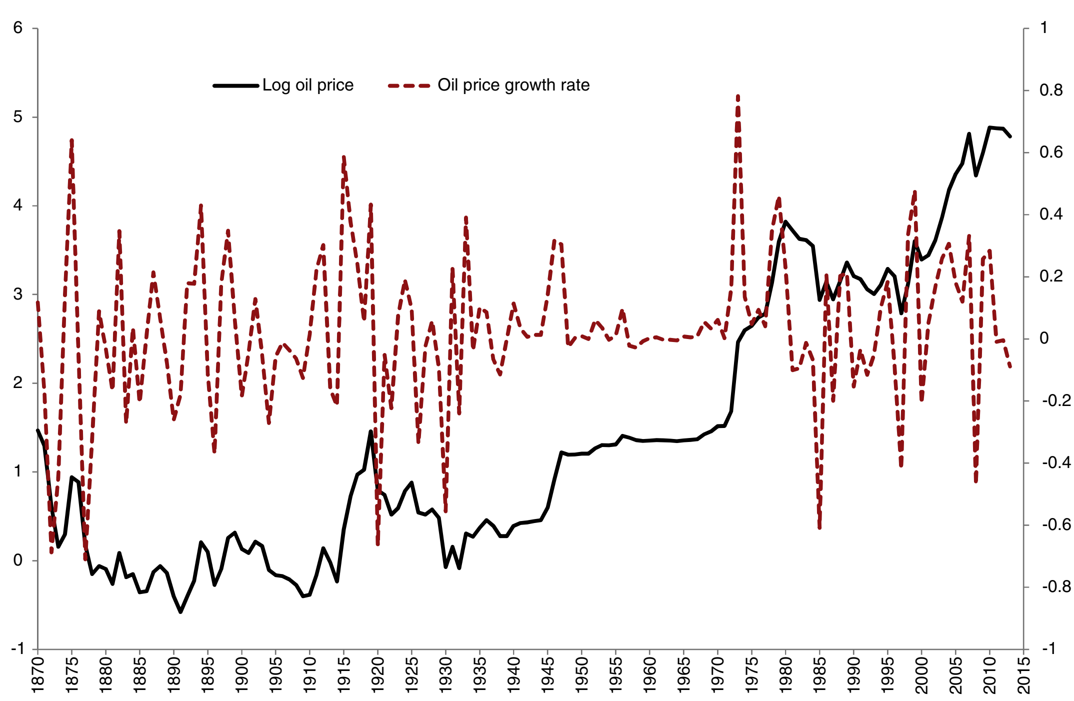

Fig. 1. Logged oil price and its growth rate.