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A supply and demand based volatility model for energy prices ☆

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ABSTRACT

This paper proposes a new volatility model for energy prices using the supply–demand relationship, which we call a supply and demand based volatility model. We show that the supply curve shape in the model determines the characteristics of the volatility in energy prices. It is found that the inverse Box–Cox transformation supply curve reflecting energy markets causes the inverse leverage effect, i.e., positive correlation between energy prices and volatility. The model is also used to show that an existing (G)ARCH-M model has the foundations on the supply–demand relationship. Additionally, we conduct the empirical studies analyzing the volatility in the U.S. natural gas prices.

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1. Introduction

High volatility in price returns often appears in deregulated energy markets. The market participants such as energy producers and distributors always face such high volatility risks from energy markets. As a simple example to illustrate the influence of the volatility, let us think of a thermal power plant procuring natural gas as the fuel from the spot market. Since the natural gas prices are volatile due to the supply and demand in the market, the risk manager in charge of the procurement of natural gas needs to capture the volatility as accurately as possible by using an energy volatility model. The volatility models have been introduced into energy markets because of the needs from energy market participants as described in the above example.

Although a lot of volatility models both in continuous and discrete time were developed in financial markets, they are directly applied to the volatility models in energy markets without any adjustment for the energy characteristics. The continuous time models in stock markets, such as Heston model introduced by Heston (1993) and C.E.V. (Constant Elasticity of Variance) models developed by Cox (1975) and extended by Emanuel and MacBeth (1982), are directly used for the models in energy markets (e.g., Eydeland and Wolyniec (2003)). Similarly, the discrete time models such as ARCH, GARCH, and ARCH-M models in Engle (1982), Bollerslev (1986), and Engle et al. (1987) are employed in energy market models in Duffie et al. (1999), Pindyck (2004), and Deaves and Krinsky (1992), respectively. Energy markets may utilize the same volatility models as financial markets. However, the volatility in energy markets is not necessarily the same as the volatility in stock markets. For instance, the "inverse leverage effect", i.e., volatility increases in prices, often appears in energy markets, while the analyses in stock markets illustrate the opposite relationship between the volatility and the prices.

Energy price models have been developed as asset pricing models in commodity markets. Gibson and Schwartz (1990) propose a two-factor model for crude oil in which the log of spot price follows a normal process and the convenience yield follows a mean reverting process. Brennan (1991) also models commodity spot prices and convenience yields as separate stochastic processes with a constant correlation. Schwartz (1997) compares one-, two-, and three-factor models in which the log of spot price follows a simple stochastic process to describe commodity prices. One relevant paper in this class is Kolos and Ronn (2008) where energy forward price returns precisely demonstrate volatility-in-mean effect. While these models work well to describe energy prices, supply and demand relationship of energy is not explicitly structured in the models. This paper proposes the SDV model for energy prices that can accurately demonstrate the characteristics of volatility in energy prices using the supply–demand relationship.

We show time series of demand and price for natural gas in the U.S. in Fig. 1. The figure seems to suggest that prices increase in demand, especially in recent years because peaks of prices correspond to peaks of demand. In order to express the curve using a simple model, we introduce an equilibrium price model determined by the inelastic demand curve fluctuating stochastically and the upward-sloping supply curve fixed in a

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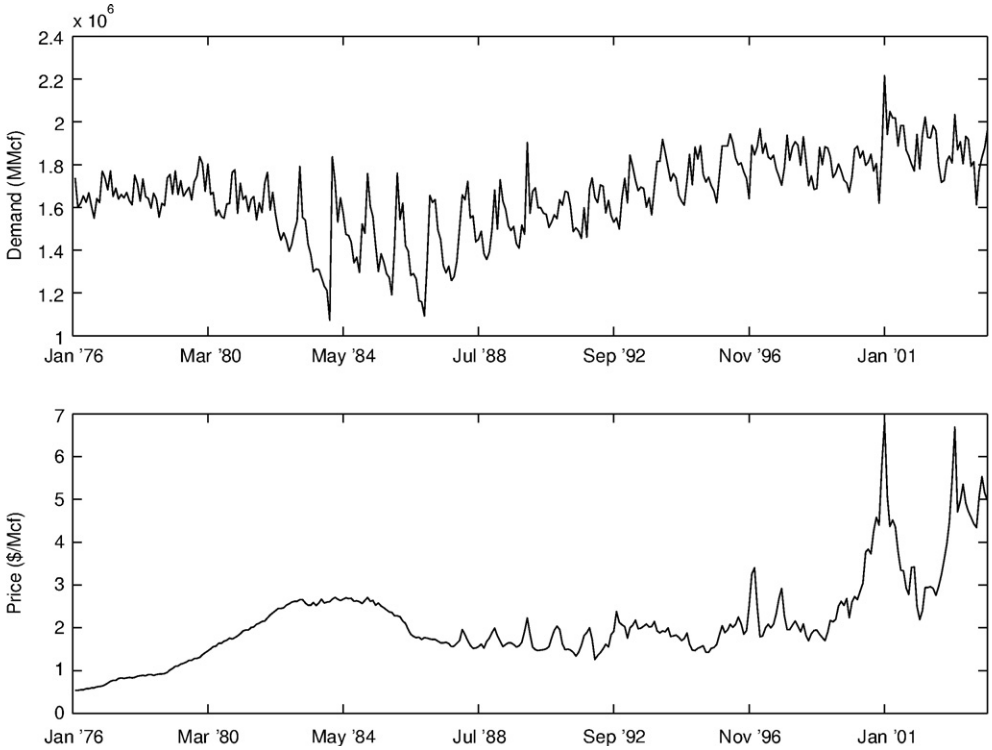

Fig. 1. The relationship between demand (= supply) and prices.

short period of time, what we call a supply and demand based volatility (SDV) model. We show that the SDV model provides twofold characteristics of the volatility in energy price returns. First, the volatility is time varying owing to both the upward-sloping supply curve and demand shocks. Second, the mean of price returns changes with the volatility, which we call "volatility-in-mean effect", due to the drift term of price returns represented by the function of the volatility. Then, we specify the model by employing the inverse Box–Cox transformation supply curve that can exhibit the drastic slope changes with an appropriate function parameter. It is found that the model can produce both the inverse leverage effect and volatility-in-mean effect. In addition, getting an idea from the volatility-in-mean effect, we investigate the relationship between the discrete time SDV model and (G)ARCH-M model. We show that an existing (G)ARCH-M model has the foundations on the supply–demand relationship.

We conduct the empirical analyses on the volatility in the U.S. natural gas prices by using the SDV model and the implications from the model. First, in an effort to examine the existence of the inverse leverage effect in the U.S. natural gas market, we identify the model parameters of the inverse Box–Cox supply curve employing nonlinear least squares. Both monthly equilibrium prices and demands are used for the identification, supposing that the sum of consumption and storage demands approximates to the equilibrium demand. The results illustrate that the extremely large change of the gradient causes the inverse leverage effect in the natural gas market. Second, we examine the existence of the volatility-in-mean effect in the natural gas market by using GARCH(1,1)-M model linked to the discrete time SDV model. It is found that the estimation results support the existence of volatility-in-mean effect.

Finally, we empirically investigate the validity of two assumptions in this paper. The first assumption is that the sum of consumption and storage demands approximates to the equilibrium demand. The second assumption is that demand is inelastic to prices in the SDV model. We show that both assumptions hold as the first order approximation.

The remainder of this paper is organized as follows. Section 2 proposes a new model for time-varying volatility in energy prices, what we call SDV model and then investigates the relationship between the SDV model and existing (G)ARCH-M models. Section 3 conducts empirical studies on the volatility in the U.S. natural gas prices in attempts to examine the existence of the inverse leverage and volatility-in-mean effects as the characteristics of the price volatility. Section 4 addresses the validity of the assumption on the equilibrium demand. Section 5 identifies the simultaneous equations for the supply and demand curves of the natural gas market by implementing the nonlinear two-stage least square estimation in order to assess the validity of the demand inelasticity assumption. Section 6 concludes and offers the directions for our future research.

2. The model

2.1. A supply and demand based volatility (SDV) model for energy prices

Fig. 1 illustrates the relationship between monthly equilibrium demands and prices for natural gas in the U.S.[1] As we see, the prices seem to increase in demand. The market observation has motivated us to incorporate the supply–demand relationship directly into the energy spot price model, i.e., the volatility model. In order to build the model up, we employ the simplified relationship between the demand and price for energy as follows.

As in Fig. 2, we assume that the equilibrium prices are determined by the fixed increasing supply curve and the stochastically fluctuating vertical demand curve. The assumption of the fixed supply curve comes from the observation on energy markets, i.e., both the number and constitution of the production facilities are almost kept constant in a short term. The assumption of the vertical demand curve arises

[1] We use well head prices and total demand for natural gas.

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