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A tale of two regimes: Theory and empirical evidence for a Markov-modulated jump diffusion model of equity returns and derivative pricing implications

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ABSTRACT

We provide closed-form solutions for a continuous time, Markov-modulated jump diffusion model in a general equilibrium framework for options prices under a variety of jump diffusion specifications. We further demonstrate that the two-state model provides the leptokurtic return features, volatility smile, and volatility clustering observed empirically for the Dow Jones Industrial Average (DJIA) and its component stocks. Using 10 years of stock return data, we confirm the existence of jump intensity switching and clustering, illustrate transition probabilities, and verify superior empirical fit over competing Poisson-style models.

1. Introduction

Leptokurtic and asymmetric stock return distributions, the volatility smile, and volatility clustering are critical empirical observations that have made the consistent theoretical description of asset prices elusive, especially in the case of options. The literature provides two general modeling directions to capture these features: the stochastic volatility class of models, such as Hull and White (1987), Duan (1995), Heston (1993), Heston and Nandi (2000), and Stein and Stein (1991), and the jump diffusion class of models, such as those of Björk et al. (1997) and Glasserman and Kou (2003).[2]. They capture leptokurtosis and the volatility smile but generally do not explain volatility clustering because increments are assumed to be independent in both the diffusion and the jump.

In this paper, we propose a Markov-modulated jump diffusion model (MMJM), in which the jump frequency of the underlying asset changes over time according to the state of the economy, which is governed by a continuous Markov chain. The jump behavior, in turn, affects option and stock prices. In the simplest case where there are only two states, we illustrate that periods of high (low) jump arrivals tend to be followed by periods of continued high (low) jump arrivals, which results in jump clustering.[3] By investigating the Dow Jones Industrial Average (DJIA), we document this phenomenon empirically and attribute it to extended periods of sustained structural abnormality such as the credit crisis or the dotcom bubble. Whereas PJMs only capture abnormal price movements resulting from information events or surprises, MMJMs add color

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2 Some models, such as those of Pan (2002), Bakshi et al. (1997), Eraker (2004), and Bates (2000) consider stochastic volatility with jump risks.

3 Markov processes are often referred to as a "regime-switching" process when there are only two states in the chain.

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by allowing for extended periods of abnormality that may result in periods with frequent jumps in which prices may react with heightened sensitivity to the arrival of information, depending on their states. This clustering of jumps results in volatility clustering during the high-jump-frequency state. We empirically document the existence of these excited or quiet states and demonstrate the superior empirical fit of our model over PJMs.

Our model is not the first of the MMJMs. This class of models may introduce variation into the asset pricing process through the drift, Normal diffusion, or abnormal variation (jump) attributes. As previously mentioned, because it is Markov-modulated, each variation "holds" for a period of time, which is an important distinction from the more general class of stochastic volatility models. Elliott et al. (2007) and Bo et al. (2010) investigate general Markov-modulated jump diffusion models in which the market interest rate, jump frequency, drift and volatility of the underlying asset price vary over time, governed by a continuous Markov chain; the latter focus on currency options. These models are developed in the discrete time context, do not provide closed-form solutions, and hence do not address empirical fit.

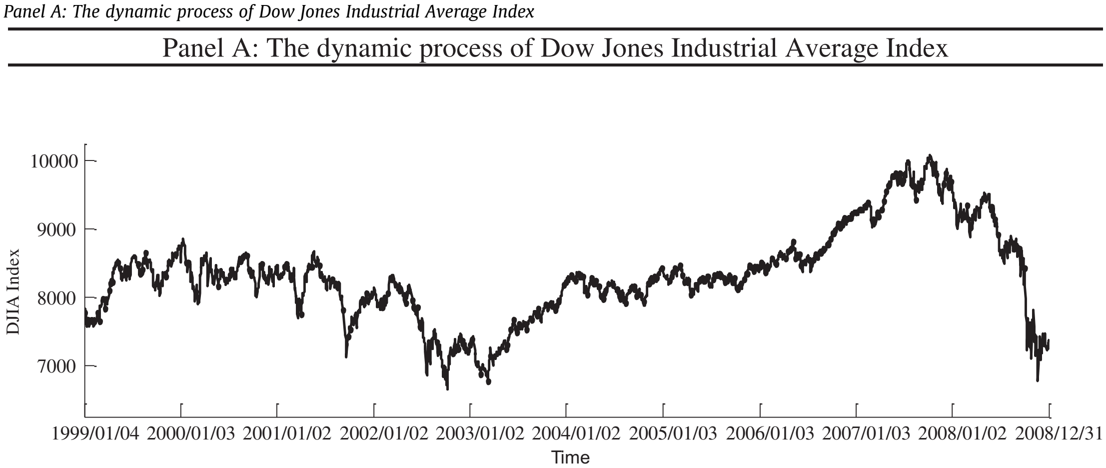
Elliott and Siu (2011) incorporate structural changes in economic conditions, such as financial crises, into the description of price dynamics, and Chen (2010) uses an MMJM to indicate how business cycles impact prices. These demonstrate the intuitive attractiveness of this class of models because they naturally fit the state-dependent nature of MMJM, emphasizing the characteristic that the economy stays in each state for an extended period rather than varying at all points. Catastrophe- or weather-based assets such as insurance or certain futures may be valued in this way. Similarly, MMJMs may also be used to model periods of high asset co-integration for collapse models. In general, however, these MMJMs address the continuous component of volatility, allowing for mean-reverting qualities of volatility. To our knowledge, ours is the first to isolate the impact of jump behavior and the jump clustering phenomenon.

In this paper, we choose to model stochastic volatility as a MMJM for two main reasons. First, the literature, along with the findings of this study, documents strong empirical evidence of jump behavior that is not generated in Poisson-type stochastic volatility models, including Ball and Torous (1983, 1985), Beckers (1981), Bates (1991), and Eraker et al. (2003). Second, empirical observations and anecdotal evidence show that jumps in equity markets are not independent but seem to come in bursts, with certain periods being more prone to jumps than others; i.e., we empirically observe jump clustering. The internet bubble period and recent financial crisis are two examples of such jump-sensitive periods, representing boom and bust periods, respectively. Björk et al. (1997) and Glasserman and Kou (2003) each study jump

Table 1

Evidence from Dow Jones index and return. Table 1 plots the dynamics of the Dow Jones Industrial Average index and its return from 1999/1/4 to 2008/12/31. In Panel A, we show the Dow Jones Industrial Average, and Panel B is we graph returns of the DJIA. Horizontal bands about 0% indicate a ±3% band, where returns outside of the band may be seen as jumps. Periods with few such jumps are considered quiet, those with more jumps are considered excited.

Panel A: The dynamic process of Dow Jones Industrial Average Index



Panel B: Extreme returns on the Dow Jones index