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Jumps in Oil Prices – Evidence and Implications

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Abstract

This paper studies the dynamic behavior of daily oil prices and finds strong evidence of GARCH as well as conditional jump behavior. This implies that conditional heteroscedasticity is present and the empirical distribution of oil price changes has heavy tails. Thus, the oil price considerably sensitive to news and does not settle around a long-run trend. This finding has several important implications: First, this financial market variable-type behaviour hampers finding optimal depletion paths of oil as exhaustible resource as well as optimal decisions regarding the transmission to alternative technologies. Second, as the usage of oil is one of the main sources of carbon emissions, this non-existence of a clear long-run trend is likely to cause a current overextraction of oil, accompanied by severe consequences for the global climate.

JEL Code: C22, Q30.
Keywords: Oil price, conditional jumps, GARCH, Hotelling, climate change.

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1 Introduction

The oil price is subject of a vast literature, consisting of theoretical as well as empirical papers. Three main approaches to explain the behavior of the price of oil exist in the literature: there is, first, Hotelling's (1931) notion that oil is an exhaustible resource and that the price of which exhibits a long-run upward trend. Various extensions of this original model have been proposed, see Krautkraemer (1998) and Sinn (2008) for comprehensive summaries. Second, papers such as Krichene (2002) and Dees et al. (2007) attempt to explain the oil price using macroeconomic supply and demand frameworks. Third, Dees et al. (2008) and Kaufmann and Ullman (2009) investigate the oil price behavior in a more informal way and focus on issues such as OPEC power and the role of speculation.[1] Another important strand of literature is concerned with the issue of whether a deterministic trend is present in non-renewable resource prices. The results, however, are not unambiguous: while Slade (1988) finds evidence of stochastic trends, Slade (1982) and Lee et al. (2006) conclude that quadratic trends and deterministic trends with structural breaks, respectively, are present. Pindyck (1999), finally, promotes the view that the real oil price fluctuates around a long-term trend which itself is fluctuating stochastically.

The oil price, furthermore, attracted considerable attention from the area of financial econometrics. An enormous amount of papers dealing with issues such as oil price volatility [Foster, 1995; Pindyck, 2004a,b], hedging [Lien et al., 2002], and oil price forecasts [Morana, 2001; Moshiri and Foroutan, 2006] emerged from these research efforts. Askari and Krichene (2008) and Agnolucci (2009) are amongst the most recent papers. These papers, mainly, use daily oil price data and employ sophisticated empirical techniques. Even the pure fact that techniques such as GARCH models, artificial neural networks and jump-diffusion processes are used signals that the oil price's behavior is somehow peculiar. Hamilton's (2008) survey-paper confirms this and summarizes that "changes in the real price of oil have historically tended to be (1) permanent, (2) difficult to predict, and (3) governed by very different

[1] Fattouh (2007) provides a useful summary of this literature.

regimes at different points in time."

The vast majority of the econometric papers mentioned above, however, are interested in the technical performance of their models rather than in theoretical implications of their results. A notable exception is this regard is Pindyck (1999). The paper explicitly relates its empirical findings to standard resource economic frameworks as well as the question of how to adequately model investment decisions.

This paper's contribution to the literature is twofold. First, it applies Chan and Maheu's (2002) auto-regressive jump-intensity (ARJI)-GARCH model to daily oil price data from March 1983 to November 2008 in order to get a better understanding of the oil price's behavior. Jump models, in general, have proven to be a useful tool for capturing events such as unexpected news and sudden price movements. The usage is further motivated by considerably small price elasticities of both oil supply and demand and correspondingly large price movements in order to clear even small excess supply or demand situations [Askari and Krichene, 2008]. The distinct feature of ARJI-models is that they allow the jumps to occur at differing size and frequency. This model class and bivariate extensions of which have been successfully applied to stock market returns [Chan and Maheu, 2002], exchange rates [Chan, 2003; Chan, 2004], and copper prices [Chan and Young, 2006]. This paper joins the oil price to this list and, thus, extends the work by Askari and Krichene (2008) by applying time-varying rather than time-invariant jump-intensity models. As per Pindyck (1999), secondly, it relates its empirical findings to a number of theoretical considerations. Hotelling (1931), for instance, developed a famous rule according to which the price of an exhaustible resource, in optimum, grows at the rate of interest. Sinn (2008) emphasizes that oil is also one of the main sources of carbon emissions and, in turn, extends Hotelling's (1931) work by considering the issue of global warming. It is shown that ignoring global warming leads to a current overextraction of oil. What is more, Holland (2008) shows that information extracted from the price of oil is crucial for decisions regarding transition to alternative technologies and shows that the oil price is the better scarcity indicator than oil production is.

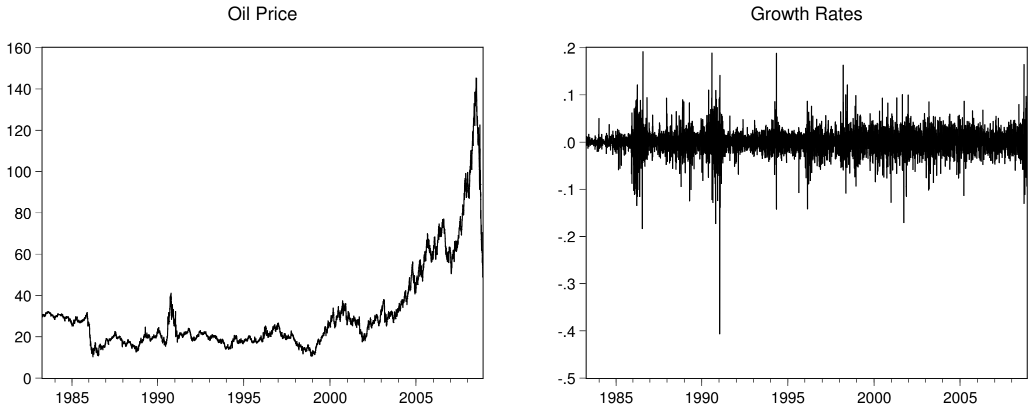
The following key results emerge from this paper. Applying Chan and Maheu's (2002) methods yields strong evidence of GARCH behavior as well as conditional jump-intensity in daily oil price changes. This implies that conditional heteroscedasticity is present and the empirical distribution of oil price changes has heavy tails. What is more, the oil price is very sensitive to news and, in consequence, does not settle around a long-term trend. The theories sketched above, however, imply that the oil price path is generally upward trending and that certain information is to be extracted from the price of oil. This paper's empirical findings suggest that it is doubtful that the oil price can reliably provide the information he is expected to do. This implies, first, that finding the optimal depletion path for oil as well the optimal transition to alternative technologies is hampered. What is more, the non-existence of a long-term trend is likely to cause a current overextraction of oil, which would have severe consequences for the global climate.

The remainder of this paper is organized as follows: the following Section 2 provides a descriptive analysis of the data and Section 3 outlines the Chan and Maheu (2002) method. Sections 4 and 5 present the empirical results and a discussion of which. Section 6, finally, concludes.

2 Descriptive Analysis

This section's descriptive analysis further motivates this paper's empirical approach. Figure 1's left panel displays a plot of daily oil price data. It is evident that the oil price is governed by considerably different regimes: while the 1980s and 1990s are characterized by a fairly volatile, but horizontal movement, a bubble-type behavior is present in the 2000s. The growth rates (right panel) show that the volatility is clearly not time-invariant - tranquil periods are followed by high-volatility ones and vice versa. This type of volatility clustering is well known to those who are familiar with e.g. stock return behavior. Figure 2 provides further evidence of the similarity between oil price and financial market variable behavior. The left panel displays the autocorrelation-function of the oil price's absolute growth rate. The considerably slow decay of the ACF indicates that a long-memory structure

Figure 1: Price of Oil, March 1983 - November 2008



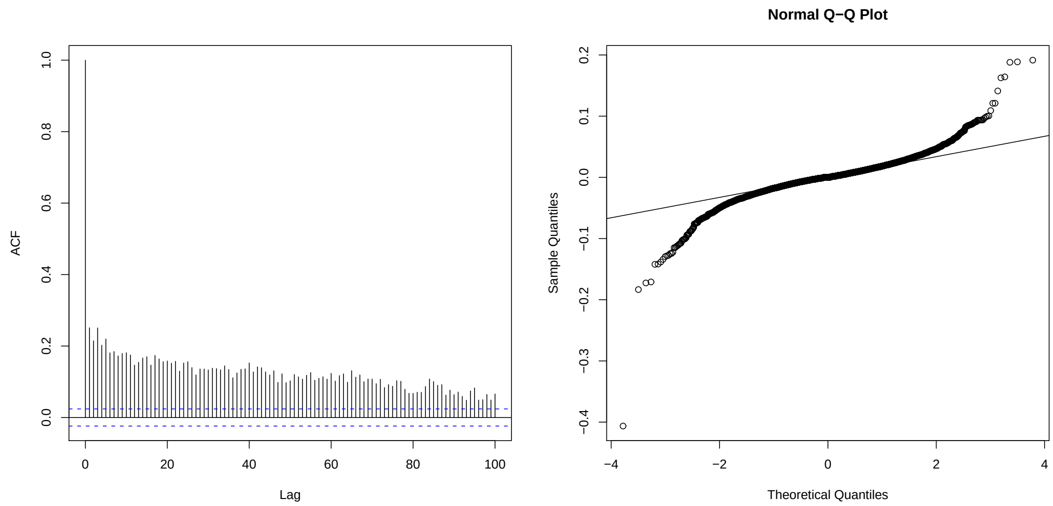
is present. The right panel depicts a plot of the empirical quantiles of the oil price changes against the theoretical quantiles of a normal distribution. It is clearly evident that the normality assumption does not hold for daily oil price changes.

The kernel density estimates displayed in Figure 3 confirm this impression. The leptokurtic structure of the oil price's growth rate is evident. The comparison to normal densities shows that extreme price movements occur considerably more often than under the normality assumption - heavy tails are present. Moreover, large negative changes appear to be more likely than large positive ones. In general, features such as long-memory as well as heavy tails are frequently found in various types of financial market variables. This needs to be taken into account when it comes to empirically analyzing oil price data. Models such as the ARJI-GARCH model proposed by Chan and Maheu (2002) have proven to be useful in this regard. The following section outlines this method.

3 Method

The Chan and Maheu (2002) method applied in this paper combines conditional jump with frequently applied GARCH models. Consider the following

Figure 2: Descriptive Statistics I



model:

$$y_t = \mu + \sum_{i=1}^{l} \phi_i y_{t-i} + \sqrt{h_t} z_t + \sum_{k=1}^{n_t} X_{t,k} \tag{1}$$

with $z_t \sim NID(0,1)$. h_t follows a GARCH(p,q) process [Bollerslev, 1986]:

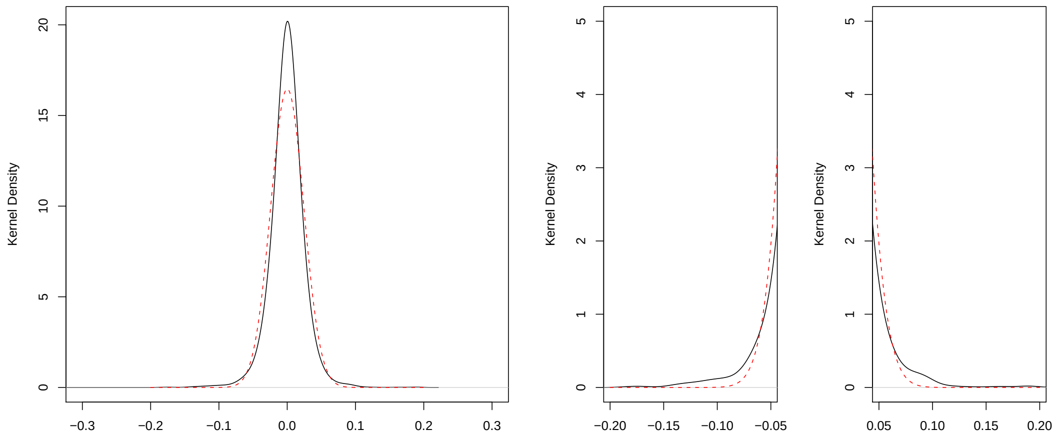
$$h_t = \omega + \sum_{i=1}^{q} \alpha_i \epsilon_{t-i}^2 + \sum_{i=1}^{p} \beta_i h_{t-i} \tag{2}$$

The conditional jump size $X_{t,k}$, given the history of observations $\Phi_{t-1} = \{y_{t-1}, \ldots, y_1\}$, is assumed to be normally distributed with mean θ_t and variance δ_t^2; n_t describes the number of jumps that arrive between $t-1$ and t and follows a Poisson distribution with $\lambda_t > 0$:

$$P(n_t = j | \Phi_{t-i}) = \frac{\lambda_t^j}{j!} e^{-\lambda_t} \tag{3}$$

λ_t is called jump-intensity. Two variants of the model are applied: a constant jump-intensity model with $\lambda_t = \lambda$, $\theta_t = \theta$, and $\delta_t^2 = \delta^2$ and a time-varying jump-intensity model. For the latter, λ_t is assumed to follow the

Figure 3: Descriptive Statistics II



Note: Displayed are kernel density estimates with a Gaussian kernel and smoothing bandwith of 0.01.

auto-regressive process

$$\lambda_t = \lambda_0 + \sum_{i=1}^{r} \rho_i \lambda_{t-i} + \sum_{i=1}^{s} \gamma_i \xi_{t-i}. \tag{4}$$

The jump-intensity residual ξ_t is calculated as

$$\xi_{t-i} \equiv E[n_{t-i}|\Phi_{t-i}] - \lambda_{t-i} = \sum_{j=0}^{\infty} jP(n_{t-i}|\Phi_{t-i}) - \lambda_{t-i}. \tag{5}$$

Using the observation x_t and Bayes rule, the probability of the occurrence of j jumps at time t can be written as

$$P(n_t = j|\Phi_t) = \frac{f(x_t|n_t = j, \Phi_{t-1})P(n_t = j|\Phi_{t-1})}{P(x_t|\Phi_{t-1})} \tag{6}$$

Chan and Maheu (2002)'s method has been successfully applied to various types of financial market data. Section 2's descriptive analysis suggests that the daily oil prices appear to be governed by a comparable data generating process. Askari and Krichene (2008) employ jump-diffusion models to oil price data, but assume the jump-intensity to be time-invariant and consider only data from 2002-2006. Thus, this study extends Askari and Krichene's (2008) as the method applied here allows for time-varying jump-intensities. The following section presents the results obtained from applying the ARJI-model to daily oil price changes.

4 Results

This section applies the Chan and Maheu (2002) method to the daily oil price data's growth rate (West Texas Intermediate, USD per barrel). The period of observation is 30/03/1983 to 24/11/2008.

Table 1 displays the estimates for both the constant and the autoregressive jump-intensity model. One lag of the endogenous variable as well as a constant are included.

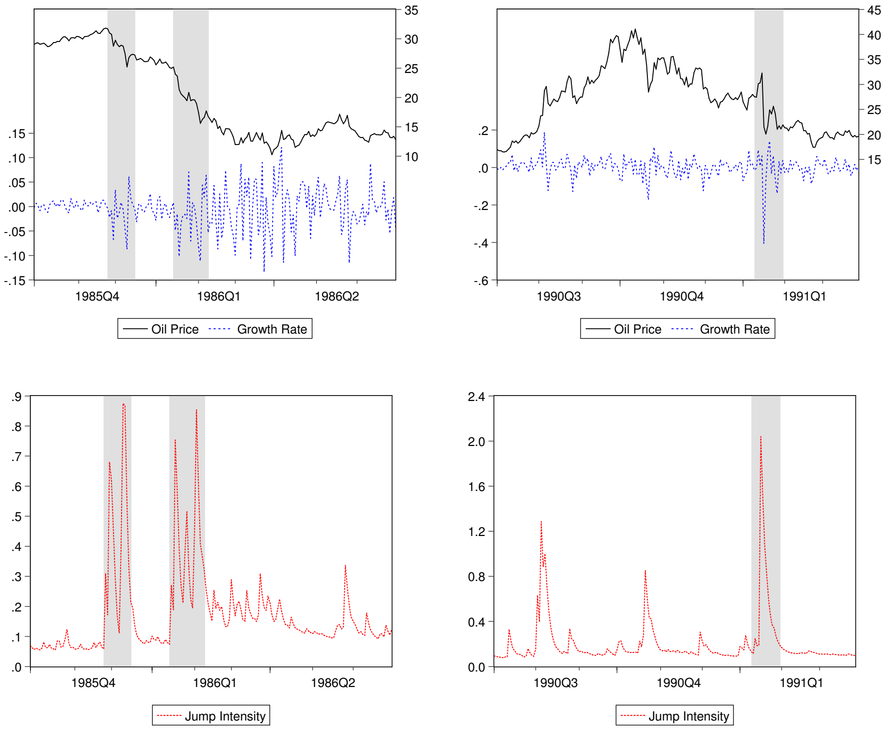
Table 1: Constant and time-varying jump-intensity models

Parameter	Constant	ARJI
μ	2.9E-04 (0.0930)	3.4E-04 (0.0384)
ϕ_1	-0.0311 (0.0167)	-0.0318 (0.0106)
ω	3.5E-07 (0.0759)	4.1E-07 (0.0387)
α	0.0613 (0.0001)	0.0390 (0.0001)
β	0.9255 (0.0001)	0.9464 (0.0001)
δ	0.0406 (0.0001)	0.0345 (0.0001)
θ	-5.7E-03 (0.0256)	-4.2E-03 (0.0173)
λ	0.0705 (0.0001)	0.0375 (0.0002)
ρ	-	0.7218 (0.0001)
γ	-	0.5319 (0.0001)

Note: p-values in parentheses.

Two key messages emerge from this exercise: first, the GARCH pa-

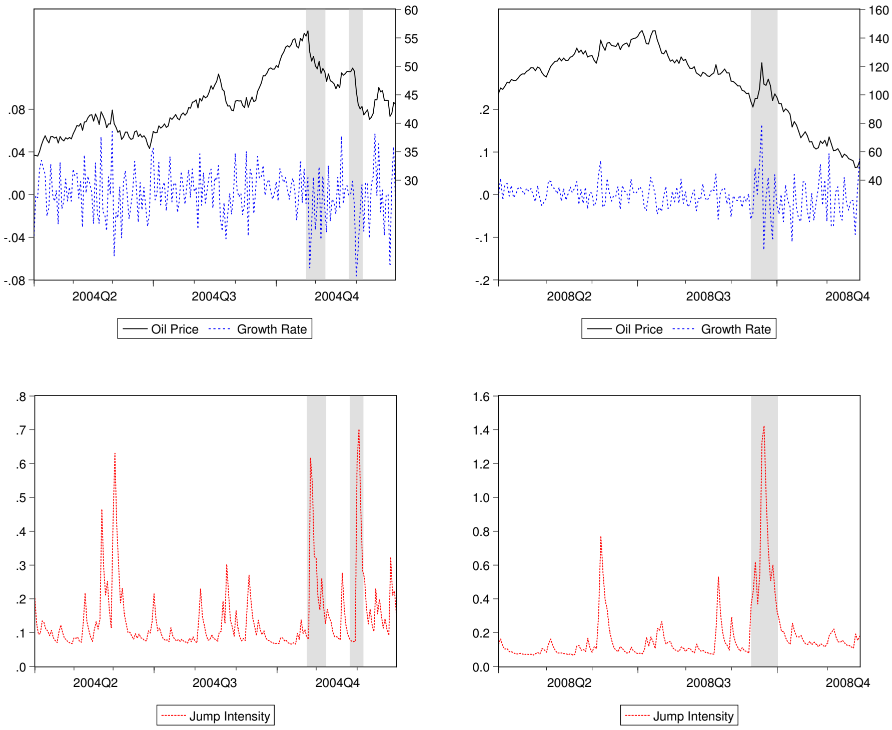
Figure 4: Autoregressive Jump Intensity I



rameters ω, α, and β are highly significant. This finding is in general in line with the literature. Second, the jump parameters in both specifications are also highly significant. Both models indicate that the mean of the jumps is negative ($\hat{\theta} = -0.0006$ and -0.0004, respectively) - a result anticipated from the descriptive analysis of Section 2. Furthermore, also the time-varying jump-intensity parameters are highly significant. The estimate of the AR-component indicates that the jump-intensity is slightly persistent ($\hat{\rho} = 0.7218$).

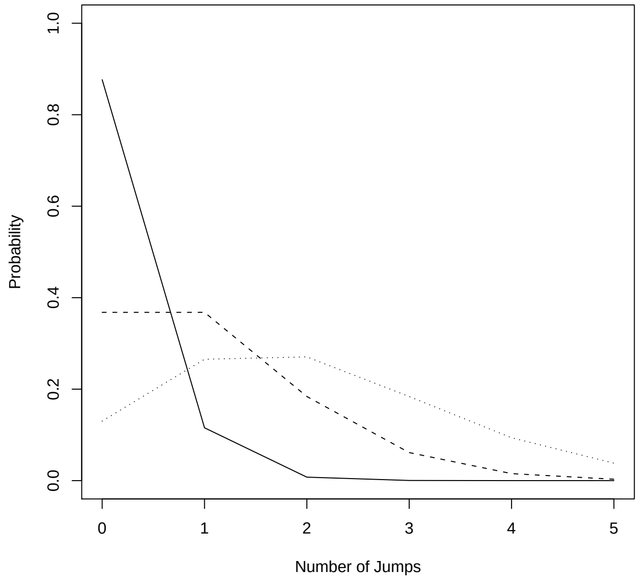
The following detailed analysis further illustrates the adequacy of this method and yields additional interesting insights. Considered are the following four major oil price events: (1) the 1986 OPEC collapse, (2) the largest oil price drop in 1991, (3) the begin of the oil price surge in 2003, and, (4) the recently witnessed oil price downfall. The OPEC collapse is considered a major break in the oil price series, see e.g. Lee et al. (1995) and Gron-

Figure 5: Autoregressive Jump Intensity II



wald (2008). Moreover, the oil price movements witnessed after 2000 are still subject of scientific investigations [Askari and Krichene, 2008]. Figure 4 presents, for each event, the oil price level, the growth rate and the time-varying jump-intensities, expressed by the λ-parameters obtained from the estimated ARJI-model. Regarding the first sub-period (see the left panel in Figure 4), the plots of both the level and the change of oil prices vividly illustrate the change in the oil price behavior. The overall decline from about USD 30 to less than USD 15 appears to take place in a number of larger declines. Between these larger declines rather horizontal movements are present. The large declines, however, lead to considerable increases in the jump-intensities from less than 0.05 to peaks of about 0.5. Moreover, the increased volatility of the oil price is reflected by a generally larger jump-intensity in the second part of this subperiod. Hence, the ARJI-models applied here appear to be useful for capturing this peculiar oil price behavior. The remaining

Figure 6: Autoregressive Jump Intensity III



subperiods confirm this finding: the largest oil price drop leads to the largest jump intensity of about 2 (Figure 4, right panel). The absolute number of intensity-peaks in this subperiod, however, is considerably smaller. The early 2000s oil price surge consists, as indicated by the jump intensities, of a larger number of smaller increases rather than upward jumps (Figure 5, left panel). The two larger decreases in this subperiod are again well captured by the ARJI-model. Similarly, the oil price drop from USD 140 to about USD 60 in the last subperiod consists of a larger number of smaller decreases rather than negative jumps. Only two sudden increases lead to considerable increases of the jump-intensities. This analysis, furthermore, shows that jumps in the price of oil occur "only occasional", which is a possible explanation of the long-memory structure detected in Section 2.[2]

Figure 6, finally, displays theoretical Poisson distributions for different values of λ. Besides the average jump-intensity of the full sample, 0.13 (solid line), also distributions for intensities of 1, which are occasionally found (long

[2]See Granger and Hyang (2004) for a discussion of the relationship between occasional jumps and long-memory processes.

dashes), as well as 2 (maximum jump intensity, short dashes) are displayed. It is clearly evident that the probability for larger number of jumps clearly differs across the sample period.

In a nutshell, Chan and Maheu's (2002) auto-regressive jump intensity model has proven to be a useful tool for capturing the peculiar behavior of the oil price. The daily oil prices exhibit features that are well-known from various types of financial market variables. This finding emerges from both the descriptive analysis and the estimation results. The oil price is not only characterized by conditional heteroscedasticity, but also by conditional jumps. Thus, a considerable sensitivity to news is present. These results extend those obtained by Askari and Krichene (2008), who find evidence of jumps in daily oil price data between 2002 and 2006. The following section now relates these empirical findings to the theories by Hotelling (1931), Sinn (2008), and Holland (2008) sketched above.

5 Discussion

This paper's empirical findings suggest that the oil price behaves similar to various financial market variables such as stock prices and exchange rates. Recall, however, that oil is an exhaustible resource, the price of which is assumed to have a distinct behavior. What is more, the usage of oil is one of the main sources of carbon emissions. In consequence, the price of oil has important theoretical implications.

Holland (2008), for instance, argues that highly recognized peak-oil papers [Hubbert, 1956] are non-economic in the sense that they ignore price effects. In addition to that, resource economic models, in particular Hotelling-type ones, do not generate peaks in production. Therefore, Holland (2008) proposes four theoretical models that reconcile these two lines of research. The models deal with issues such as demand shifts, technological change, reserves growth and site development. Holland's (2008) core conclusion is derived from a combination of these four models. According to that, the oil price is a better indicator of resource scarcity than oil production is. This finding is, naturally, of particular importance for decisions regarding the transition to alternative technologies. Hotelling's (1931) seminal paper also sparked enormous research efforts regarding the optimal depletion paths of the resource itself. According to the well known Hotelling-rule, the price of oil grows at the rate of interest. Various extensions of Hotelling's (1931) model have been suggested, for instance the inclusion of extraction costs and the security of property rights. The most recent contribution by Sinn (2008) also considers the role of global warming. It is shown that the Pareto-optimal extraction of oil under consideration of global warming is smaller than without considering this issue. In other words, if resource owners do not take global warming into account, there is a current overextraction of oil.[3] Sinn (2008), furthermore, shows that, under certain conditions, climate policies can lead to an increase rather than a decrease of oil extraction.[4] These Hotelling-type models, however, imply that the oil price path is upward trending or U-shaped, respectively, and that certain information is to be extracted from the price of oil. The question, however, is, how this paper's empirical findings relate to these theories.

As asserted above, various studies are concerned with the behavior of the oil price. Not many of which, however, discuss theoretical implications of their empirical results. Pindyck (1999) forms an exception in this regard. He studies oil price behavior in the very long run and finds evidence of long-run trends. Due to changes in demand, extraction costs and new site discoveries, however, these trends are fluctuating over time. One conclusion is that a mean-reverting process rather than a Brownian motion is the adequate stochastic process for capturing oil price behavior in the very long run. In an earlier paper, Pindyck (1981) considers a resource extraction model with resource prices that are assumed to fluctuate around a long-run upward trend. It is shown that uncertainty about future prices clearly affects resource extraction paths. Pindyck (1981), however, admits that it is empirically not resolved whether this choice of stochastic process is appropriate or a jump-process should be used.

[3]For an earlier, "non-Hotelling" consideration of this issue see Withagen (1994).

[4]The optimal design of carbon taxes is also investigated by Hoel and Kverndokk (1996) as well as Grimaud and Rouge (2008).

This paper's empirical findings suggest that assuming the oil price to follow a upward trend is, at any rate, debatable. Strong evidence of conditional heteroscedasticity and heavy tails in the empirical distribution of oil price changes is found. What is more, there is also evidence of conditional jumps, which implies that the oil price is sensitive to news and does not settle around a long-term trend. These results are at odds with the notion of deterministic trends in oil prices promoted by Slade (1982) and Lee et al. (2006) for petroleum prices, but overlap with Pindyck's(1999) stochastically fluctuating trends in real oil prices.[5] In any case, the theories by Hotelling (1931), Sinn (2008), and Holland (2008) need to be extended by explicit assumptions about the resource price behavior. Using a jump process appears to appropriate in this regard.

It is not unlikely that this will alter the model outcomes. Dixit and Pindyck's (1994) consideration of different stochastic processes in real option models clearly shows that assumptions regarding this process are crucial for the optimal investment rule.[6] Most certainly, decisions regarding oil extraction paths and the transition to alternative technologies are not as straightforward as suggested by Holland (2008). What is more, the non-existence of a long-run trend is likely to cause a current overextraction of oil. Following Sinn (2008), this would have severe consequences for global climate.[7]

This paper's empirical findings are also a possible explanation for the frequent failure in empirically confirming Hotelling-type rules. Krautkraemer (1998) as well as Krautkraemer and Toman (2003) provide excellent surveys of this literature. Neither in the oil price itself nor in the corresponding in-situ values a stable long-term trend was found. The consideration of extensions

[5] It should be noted that Pindyck's (1999) empirical approach also allows for downward sloping trends.

[6] See Baker et al. (1998) for a similar discussion.

[7] Admittedly, the sample used in this paper is March 1983 - November 2008. It remains an open question whether preceding oil price movements are also characterized by conditional jump behavior. It is, however, reasonable to assume that the oil price behavior will not generally change in the near future. Furthermore, it is also reasonable to assume that resource owners form their expectations regarding future oil price movements on this period rather than tranquil periods many years ago.

including new site discoveries certainly improved the model performance; but the general finding that the oil price does not behave like a price of a exhaustible resource remains.[8] This, as it were, is not too surprising in the sense that many financial market variables have "their own life" and can often not fully explained by fundamental facts.

6 Conclusions

The price of oil exhibits a more than peculiar behavior in the past few decades. Subsequent to the oil crises of the 1970s and the OPEC collapse in the mid-1980s, a high-volatile, but horizontal movement has been apparent. The 2000s began with a long-lasting increase, peaking at about 150 US Dollar per barrel, followed by the unforeseeable crash-like decline in the past few months.

Having a sufficient understanding of oil price dynamics is important for a number of reasons. Exemplarily, a strong link exists between uncertainty about future oil prices and investment behavior. The irreversible investment literature emphasizes the inverse relationship between uncertainty and investment caused by the option value of waiting for a better time to invest [Bernanke, 1983; Dixit and Pindyck, 1994]. Furthermore, oil price shocks make parts of the existing capital stock obsolete [Finn, 2000]; which, naturally, also affects investment decisions.

The price of oil is also a crucial part of various theories in the area of environmental and resource economics. According to Hotelling's (1931) rule, the price of an exhaustible resource grows at the rate of interest. The paper sparked enormous research efforts; Sinn's (2008) inclusion of global warming is one of the most recent contributions. Moreover, Holland (2008) reconciles the non-economic peak-oil literature with Hotelling-type theories and shows that the oil price is a better indicator of scarcity than oil production is.

This paper applies autoregressive jump-intensity GARCH models proposed by Chan and Maheu (2002) to daily oil price data from March 1983

[8] Dvir and Rogoff's (2009) application of a storage rather than an exhaustible resource model in order to describe the oil price in the very long run epitomizes this finding.

to November 2008. Jump models have proven to be a useful tool for modeling unexpected news and sudden price changes and have been successfully applied to various types of financial market variables. This paper joins the oil price to this list and finds strong evidence of time-varying jump-intensity GARCH behavior. This implies that the oil price is sensitive to news and, in consequence, does not settle around a long-run trend.

In a way, these findings nourish concerns regarding the adequacy of Hotelling-type models for oil price modeling purposes. Holland (2008), for instance, admits that, "given substantial short-run volatility in oil prices, it may be difficult to identify the underlying, long-run price trend from short-run changes in prices". What is more, Hamilton (2008) concludes that "many economists often think of oil prices as historically having been influenced little or none at all by the issue of exhaustibility". In the same vein, Dvir and Rogoff (2009) employ a storage rather than a Hotelling model in order to model oil price behavior in the very long run. Krautkraemer (1998), finally, provides evidence of regular failure in empirically testing Hotelling-type hypotheses.

This paper's empirical findings are at odds with the view of deterministic trends in oil prices. The presence of heavy tails in the empirical distribution of oil price changes as well as of conditional jumps indicate that the oil price does not settle around a long-run trend. Thus, appropriate stochastic processes need to be used in Hoteling-type models such as those by Sinn (2008) and Holland (2008) - jump processes appear to be useful in this regard. This is likely to affect the model outcomes. It is self-evident that this peculiar behavior of the oil price hampers finding both optimal extraction paths and the optimal development of alternative technologies. What is more, the non-existence of a long-term upward trend is likely to cause a current overextraction of oil, which has severe consequences for the global climate and, thus, for one of the greatest challenges of mankind.

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References

Agnolucci, P. (2009). "Volatility in Crude Oil Futures: A Comparison of the Predictive ability of GARCH and Implied Volatility Models", *Energy Economics* 31: 316-321

Askari, H. and N.Krichene (2008). "Oil Price Dynamics (2002-2006)", *Energy Economics* 30: 2134-2153

Baker, M.P, E.S.Mayfield and J.E.Parsons (1998). "Alternative Models of Uncertain Commodity Prices for Use with Modern Asset Pricing Methods", *The Energy Journal* 19: 115-148

Bernanke, B.S. (1983). "Irreversibility, uncertainty, and cyclical investment", *Quarterly Journal of Economics*: 85-106

Chan, W.H. (2003). "A correlated bivariate Poisson Jump Model for Foreign Exchange", *Empirical Economics* 28: 669-689

Chan, W.H. (2004). "Conditional correlated Jump Dynamics in Foreign Exchange", *Economics Letters* 83: 23-28

Chan, W.H. and J.M.Maheu (2002). "Conditional Jump Dynamics in Stock Market Returns", *Journal of Business & Economic Statistics* 20: 377-389

Chan, W.H. and D. Young (2006). "Jumping Hedges: an Examination of Movements in Copper Spot and Futures Markets", *Journal of Futures Markets* 26: 169-188

Dees, S., P.Karadeloglou, R.K.Kaufmann, and M.Sanchez (2007). "Modelling the World Oil Market: Assessment of a Quarterly Econometric Model", *Energy Policy* 35: 178-191

Dees, S., A. Gasteuil, R.K. Kaufmann and M. Mann (2008). "Assessing the Factos behind Oil Price Changes", *ECB Working Paper 855*

Dixit, A.K. and R.S.Pindyck (1994). "Investment under Uncertainty", Princeton University Press, Princeton

Dvir, E. and K.S.Rogoff (2009). "Three Epochs of Oil", *NBER Working Paper Series* No. 14927

FATTOUH, B. (2007). "The Drivers of Oil Prices: The Usefulness and Limitations of Non-Structural Model, the Demand-Supply Framework and Informal Approaches", *Oxford Institute for Energy Studies WPM 32* 30: 2134-2153

FINN, M.G. (2000). "Perfect Competition and the Effects of Energy Price Increases on Economic Activity", *Journal of Money, Credit and Banking* 32, 400-416

FOSTER, A.J. (1995). "Volume-Volatility Relationships for Crude Oil Futures Markets", *The Journal of Futures Markets* 15: 929-951

GRANGER, C.W.J. AND N.HYANG (2004). "Occasional Structural Breaks and Long Memory with an Application to the S&P 500 Absolute Stock Returns", *Journal of Empirical Finance* 11: 399-421

GRIMAUD, A. AND L.ROUGE (2008). "Environment, Directed Technical Change and Economic Policy", *Environmental and Resource Economics* 41: 439-463

GRONWALD, M. (2008). "Large Oil Shocks and the U.S. Economy: Infrequent Incidents with Large Effects", *The Energy Journal* 29: 151-170

HAMILTON, J.D. (2008). "Understanding Crude Oil Prices", mimeo, available at `dss.ucsd.edu\~jhamilto\understand_oil.pdf`

HOEL, M. AND S.KVERNDOKK (1996). "Depletion of Fossil Fuels and the Impacts of Global Warming", *Resource and Energy Economics* 18: 115-136

HOLLAND, S.P. (2008). "Modelling Peak Oil", *The Energy Journal* 29: 61-79

HOTELLING, H. (1931). "The Economics of Exhaustible Resources", *The Journal of Political Economy* 39: 137-175

HUBBERT, M.K. (1956). "Nuclear Energy and the Fossil Fuels", American Petroleum Institute Drilling and Production Practice, Proceedings of Spring Meeting, San Antonio, 7-25

KAUFMANN, R.K. AND B.ULLMANN (2009). "Oil Prices, Speculation and Fundamentals: Interpreting Causal Relations among Spot and Futures Prices", *Energy Economics*, forthcoming

KRAUTKRAEMER, J.A. (1998). "Nonrenewable Resource Scarcity", *Journal of Economic Literature* 36: 2065-2107

KRAUTKRAEMER, J.A. AND M.TOMAN (2003). "Fundamental Economics of Depletable Energy Supply", *Resources for the Future Discussion Paper Series* No. 03-01

KRICHENE, N. (2002). "World Crude Oil and Natural Gas: a Demand and Supply Model", *Energy Economics* 24: 557-576

LEE, K., S. NI AND R. RATTI (1995). "Oil Shocks and the Macroeconomy: the Role of Price Variability", *The Energy Journal* 16: 39-56

LEE, J., J.A.LIST AND M.C.STRAZICICH (2006). "Non-Renewable Resource Prices: Deterministic or Stochastic Trends?", *Journal of Environmental Economics and Management* 51: 354-370

LIEN, D., Y.K.TSE AND A.K.C.TSUI (2002). "Evaluating the Hedging Performance of the Constant-Correlation GARCH Model", *Applied Financial Economics* 12: 791-798

MORANA, C. (2001). "A Semiparametric Approach to Short-Term Oil Price Forecasting", *Energy Economics* 23: 325-338

MOSHIRI, S. AND F.FOROUTAN (2006). "Forecasting Nonlinear Crude Oil Future Prices", *The Energy Journal* 27: 81-95

PINDYCK, R.S. (1981). "The Optimal Production of an Exhaustible Resource when Price is Exogenous and Stochastic", *Scandinavian Journal of Economics* 83: 277-288

PINDYCK, R.S. (1999). "The Long-Run Evolution of Oil Prices", *The Energy Journal* 20: 1-26

PINDYCK, R.S. (2004A). "Volatility in Natural Gas and Oil Markets", *Journal of Energy and Development* 30: 1-21

PINDYCK, R.S. (2004B). "Volatility and Commodity Price Dynamcis", *The Journal of Futures Markets* 24: 1029-1047

SINN, H.W. (2008). "Public Policies against Global Warming: A Supply Side Approach", *International Tax and Public Finance* 15: 360-394

SLADE, M. (1982). "Trends in Natural-Resource Commodity Prices: An Analysis of the Time Domain", *Journal of Environmental Economics and Management* 9: 122-137

SLADE, M. (1988). "Grade Selection under Uncertainty: Least Cost Last and other Anomalies", *Journal of Environmental Economics and Management* 15: 189-205

WITHAGEN, C. (1994). "Pollution and Exhaustibility of Fossil Fuels", *Resource and Energy Economics* 16: 235-242

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