UPPSALA
UNIVERSITET

Working Paper 2006:23
Department of Economics

Does Oil Price Uncertainty Transmit to Stock Markets?

Martin Ågren

Department of Economics
Uppsala University
P.O. Box 513
SE-751 20 Uppsala
Sweden
Fax: +46 18 471 14 78

Working paper 2006:23
October 2006
ISSN 1653-6975

Does Oil Price Uncertainty Transmit to Stock Markets?

Martin Ågren

Papers in the Working Paper Series are published
on internet in PDF formats.
Download from http://www.nek.uu.se
or from S-WoPEC http://swopec.hhs.se/uunewp/

Does Oil Price Uncertainty Transmit to Stock Markets?

Martin Ågren*

October, 2006

Abstract

The paper presents an empirical study of volatility spillover from oil prices to stock markets within an asymmetric BEKK model. Using weekly data on the aggregate stock markets of Japan, Norway, Sweden, the U.K., and the U.S., strong evidence of volatility spillover is found for all stock markets but the Swedish one, where only weak evidence is found. News impact surfaces show that, although statistically significant, the volatility spillovers are quantitatively small. The stock market's own shocks, which are related to other factors of uncertainty than the oil price, are more prominent than oil shocks.

JEL Classification: G10, C32

Keywords: Volatility spillover, multivariate GARCH, BEKK, oil shocks, stock market

*I am grateful for the guidance and support of my supervisors Annika Alexius and Rolf Larsson. I thank Andrei Simonov for helpful suggestions on improving the paper. Comments by seminar participants at Uppsala University, especially Johan Lyhagen, and by participants at the 2005 *Arne Ryde Workshop in Financial Economics* are much appreciated. Financial support from *Stiftelsen Bankforskningsinstitutet* is gratefully acknowledged. Send correspondence to: Department of Economics, Uppsala University, Box 513, SE-751 20 Uppsala, Sweden. Phone: +46 18 471 11 29. Fax: +46 18 471 14 78. E-mail: martin.agren@nek.uu.se.

1 Introduction

Understanding the links between financial markets is of great importance for a financial hedger, portfolio manager, asset allocator, or other financial analysts. The study of volatility spillover from one market to another is a crucial part of this issue. There exists a large literature on volatility spillover, and a variety of markets have been considered, such as the equity, the bond, and the exchange rate markets. Karolyi (1995) examines the short-run dynamics of returns and volatility between the U.S. and Canadian stock markets. Kearney and Patton (2000) study how exchange rate volatility transmits within the European monetary system prior to the unification of currencies. Furthermore, Bollerslev, Engle, and Wooldridge (1988) model the conditional covariance of returns to bills, bonds, and stocks, and find that the covariances are quite variable over time. This paper analyzes the conditional volatility of oil and stock markets. Does oil price uncertainty transmit to stock markets? The issue is studied empirically within a bivariate generalized autoregressive conditionally heteroskedastic (GARCH) model, specifically, the asymmetric BEKK model of Engle and Kroner (1995) and Kroner and Ng (1998).

It is well documented that the conditional volatilities of stock market indices change over time. Many researchers are intrigued by the causes for these changes, and a large empirical literature exists where time series data on financial and macroeconomic variables are studied in relation to stock market data. Officer (1973) is first to present evidence of a relationship between the market factor (aggregate stock market) variability and business cycle fluctuations, as measured by industrial production. Schwert (1989) performs vector autoregressions and finds weak evidence that macroeconomic volatility can predict stock market volatility. The volatility of bond returns and the growth rates of the producer price index, the monetary base, and industrial production, are used as macroeconomic variables. King, Sentana, and Wadhwani (1994) employ a different approach and estimate a multivariate factor model, where comovements in stock return volatility are induced by the volatility of a number of factors. Using data on not only the U.S. but on sixteen national stock markets, King et al. (1994) try to identify the causes for stock volatility through both "observable" factors, e.g. interest rates, industrial production and oil prices, and "unobservable" factors, which reflect the influences on stock volatility that are not captured by published statistics. Their results display little support for the observable economic variables. Instead, King et al. (1994) argue that unobservable uncertainty contributes to the variability in stock returns, and, also, to the comovements in stock volatility across national markets.

The current paper shifts focus from general macroeconomic variables to the oil price, in analyzing the time-variation of stock volatility. The focus on oil is mo-

tivated by the large literature relating oil prices to the macroeconomy. Hamilton (1983) presents an influential article, which shows that almost all U.S. recessions since the second world war have been preceded by oil shocks. Mork (1994) surveys the extensive literature on oil and the macroeconomy following Hamilton (1983), and demonstrates a clear negative correlation between oil prices and aggregate measures of output or employment. Moreover, Hamilton (1985) argues that oil shocks are exogenous events, since the causes can be attributed to historical events, e.g., the Iraq invasion of Kuwait in 1990. Since stock prices, in theory, equal the discounted expectation of future cash-flows (dividends), which are likely to be affected by macroeconomic movements, they are possibly affected by oil shocks. Also, an oil price increase acts like an inflation tax on consumption, reducing the amount of disposible income for consumers. Non-oil producing companies face higher fix costs, which are passed on to higher consumer prices. These effects decrease company wealth, lowering their dividends.[1]

There exist a few papers that link oil prices to stock markets. Jones and Kaul (1996) test whether stock markets are rational in the sense that they fully adjust to the impact of oil shocks on dividends. Studying the U.S., Canadian, Japanese, and U.K. stock markets, Jones and Kaul (1996) initially show that all the markets respond negatively to oil shocks. A cash-flow valuation model is then applied, and evidence is found that U.S. and Canadian stock indices fully account for oil shocks via the effects on dividends. In contrast, stock markets in Japan and the U.K. display larger variation, following an oil shock, than can be explained by changes in dividends. While Jones and Kaul (1996) use quarterly data, Huang, Masulis, and Stoll (1996) consider daily data on the oil futures market and the stock market, and estimate a vector autoregressive model. Evidence of a connection between oil futures returns and oil stock returns is presented. There is no such support for aggregate stock returns during the 1980s however. Sadorsky (1999) studies the impact of real oil price shocks on real stock returns by estimating vector autoregressions, including U.S. industrial production and short interest rates. The study separates positive from negative oil shocks, and, contrary to Huang et al. (1996), presents evidence that shocks to the oil price do affect aggregate stock returns. Moreover, the impact appears to be asymmetric, since positive oil shocks are of large importance, whereas negative ones have little or no effect. Basher and Sadorsky (2004), using a multi-

[1] Recently, Rogoff (2006) surveys the literature on oil shocks and the global economy, and argues that most oil consuming countries are less vulnerable to oil shocks than they were a few decades ago. The greater energy efficiency is reported as one reason. Nevertheless, Rogoff (2006) stresses that it would be very wrong to consider the oil-induced recessions as a thing of the past.

factor arbitrage pricing model, find strong evidence that oil price risk impacts returns of emerging stock markets.[2]

Most of the previous work relates the level of oil price changes to the level of stock returns, i.e., first-order moments are analyzed. The current paper demonstrates a study of oil price and stock market volatility, i.e., second-order moments are considered. Although some papers address this issue, e.g., Schwert (1989) and King et al. (1994), the present paper employs a substantially different model. The bivariate GARCH model specifies the conditional variances and covariance of oil price changes and stock returns so that, for instance, volatility spillover can be tested for in a simple manner.

Bollerslev et al. (1988) introduce multivariate GARCH (MGARCH) modeling, and propose a general parameterization of the conditional covariance matrix called VECH.[3] The VECH model does not impose any restrictions on its parameters, implying that the positive definiteness of the conditional covariance matrix is not guaranteed. The model is also quite computer-intensive in estimation, relative to other MGARCH models, because of its large number of parameters. To circumvent these problems, Engle and Kroner (1995) present the BEKK specification of the conditional covariance, and, later on, Kroner and Ng (1998) extend this model to allow for asymmetry.[4] The BEKK model is specified using quadratic forms, which guarantees positive definiteness.

This paper adopts the asymmetric BEKK (ABEKK) model to examine if oil price volatility transmits to stock market volatility. A bivariate VAR(2)-ABEKK model is estimated using weekly returns on five aggregate stock market indices and a measure of the oil world price.[5] Parameter restrictions are imposed so that stock returns do not affect oil prices, motivated by the proposed exogenity of oil shocks (Hamilton, 1985). The asymmetric effects of oil price shocks are motivated empirically by Mork, Olsen, and Mysen (1994), studying macroeconomic variables, and, as previously mentioned, Sadorsky (1999). Over the sample period from week one of 1989 to week seventeen of 2005, strong evidence of volatility spillover is found for Japan, Norway, the U.K., and the U.S. Weak evidence of volatility spillover is found for Sweden over the sample period. Although the empirical results show that volatility spills over from oil to stock markets, news impact surfaces, which illustrate the estimated

[2]Other studies relating oil to stock markets include Sadorsky (2003) and Huang, Hwang, and Peng (2005).

[3]The name stems from its use of the vech-operator, which stacks the lower-triangular elements of a square matrix into a vector.

[4]The BEKK acronym stems from an unpublished paper by Y. Baba, R. Engle, D. Kraft, and K. Kroner.

[5]VAR(2) is an abbreviation for the second order vector autoregressive model.

one-period ahead impact of an oil shock, reveal small quantative effects. The stock market's own shocks, which are related to other sources of stock market uncertainty than the oil price, have more prominent implications.

Are the obtained results sensitive to the choice of data frequency? Since stock markets respond quickly to economic uncertainty, it might be that volatility spills over at a faster pace than first examined. Therefore, a second set of estimations is carried out where the weekly oil price data is leaded one period. In this way, volatility spillover is tested within the week instead of from one week to the next. Evidence of volatility spillover is however not found, supporting the primary use of weekly data. In all, the paper deepens our knowledge of how stock markets link to oil prices.

Studying the oil price influence on stock markets is an interesting and important issue, even more so recently when the world oil price has displayed great instability. During April of 2006, the price of crude oil was in the neighborhood of (U.S.) \$70 per barrel, which is well above the price of \$20 during most of the 1990s. In a recent survey of oil in the Economist, Vaitheeswaran (2005) proposes that the explanation for the rise is that oil markets have seen an abnormal combination of tight supply, surging demand, and financial speculation. One might also consider the unstable political situation in the Middle East a candidate cause for the rise in oil prices. With these aspects in mind, is the future price per barrel of oil expected to rise even more? Not necessarily. The extensive list of oil projects financed by both governments and private firms might lead to such a great supply that even high demand economies, e.g. China, cannot prevent a future supply shock, leading to a possible decline in prices.[6] The only safe statement about oil prices in the future, Vaitheeswaran (2005) argues, is that they will continue to be highly unstable.

The remaining part of the paper is organized as follows: Section 2 presents the data set used. The statistical model is introduced in section 3, where estimation and testing issues are discussed as well. Section 4 reports on the empirical results, and section 5 concludes.

[6]Recently, in May of 2005 the Baku-Tbilsi-Ceyhan pipeline was opened, bringing Caspian oil to the world market. When its potential is fully operated in 2009, the pipeline will carry about one million barrels of oil per day, or more than one percent of the world oil market.

2 Data Set

National stock markets are most likely to be affected differently by oil shocks depending of the overall country-dependence on oil. For this reason it is important to include a number of markets in the current analysis. I use a set of data consisting of aggregate stock market indices representing five developed economies, namely Japan, Norway, Sweden, the U.K., and the U.S., together with a measure of the world oil price. Each index describes the overall performance of large-capitalization firms in the respective country. Dividends are assumed reinvested at the end of each period, and, hence, accounted for in the data. Furthermore, the price per barrel Brent crude measures the world oil price.[7]

Table 1: Summary Statistics for Weekly Percentage Returns on Five National Stock Market Indices and the Oil Price

	Japan	Norway	Sweden	U.K.	U.S.	OIL
Mean (%)	-0.0404	0.176	0.206	0.185	0.209	0.128
Max. (%)	11.0	11.96	17.05	9.72	7.53	21.0
Min. (%)	-10.4	-18.21	-15.4	-8.50	-12.3	-32.7
Std. dev. (%)	2.72	2.704	2.87	2.04	2.13	5.21
Skewness	0.0434	-0.493	-0.108	-0.0626	-0.500	-0.585
Ex. kurtosis	0.96	3.538	3.01	1.63	2.99	3.21
JB	33.0* (<0.001)	478* (<0.001)	323* (<0.001)	95.1* (<0.001)	352* (<0.001)	414* (<0.001)
LBQ	11.9 (0.156)	23.67* (0.0026)	30.6* (<0.001)	5.64 (0.688)	25.3* (0.0014)	12.4 (0.133)
LBQ^2	91.4* (<0.001)	102* (<0.001)	102* (<0.001)	79.8* (<0.001)	76.4* (<0.001)	59.0* (<0.001)
ARCH LM	56.1* (<0.001)	86.9* (<0.001)	65.4* (<0.001)	64.5* (<0.001)	56.1* (<0.001)	37.9* (<0.001)

The table displays summary statistics for weekly returns on the aggregate stock markets of Japan (S&P/TOPIX), Norway (BXLT), Sweden (SIXRX), the U.K. (FTSE350), and the U.S. (S&P500), along with the price change of Brent crude oil. The sample period is from 1989:1 to 2005:17. JB is the Jarque-Bera statistic under the null of normality. LBQ (LBQ^2) is the univariate Ljung-Box Q statistic for serial correlation in returns (squared returns). ARCH LM is the Lagrange multiplier test of autoregressive conditional heteroskedasticity (Engle, 1982). All tests of correlation use eight lags. p-values are in parentheses. * indicates significance at five percent level. Data source: EcoWin Pro.

All data are at the weekly frequency (last observation of the week), and cover the first week of 1989 through week seventeen of 2005, yielding a total of 852 observations. By using weekly data the study is relieved from the noise of higher frequency

[7] The Brent blend is a light and sweet crude that ships from Sullom Voe in the Shetland Islands. It serves as a benchmark for pricing oil from regions such as Europe, Africa, and the Middle East.

data, e.g. daily or intraday, while still capturing much of the information content of stock indices and oil prices, as opposed to lower frequency data, e.g. monthly or quarterly. Moreover, the choice of data frequency differs the current analysis from previous work within the literature, where daily, monthly, as well as quarterly data have been considered.

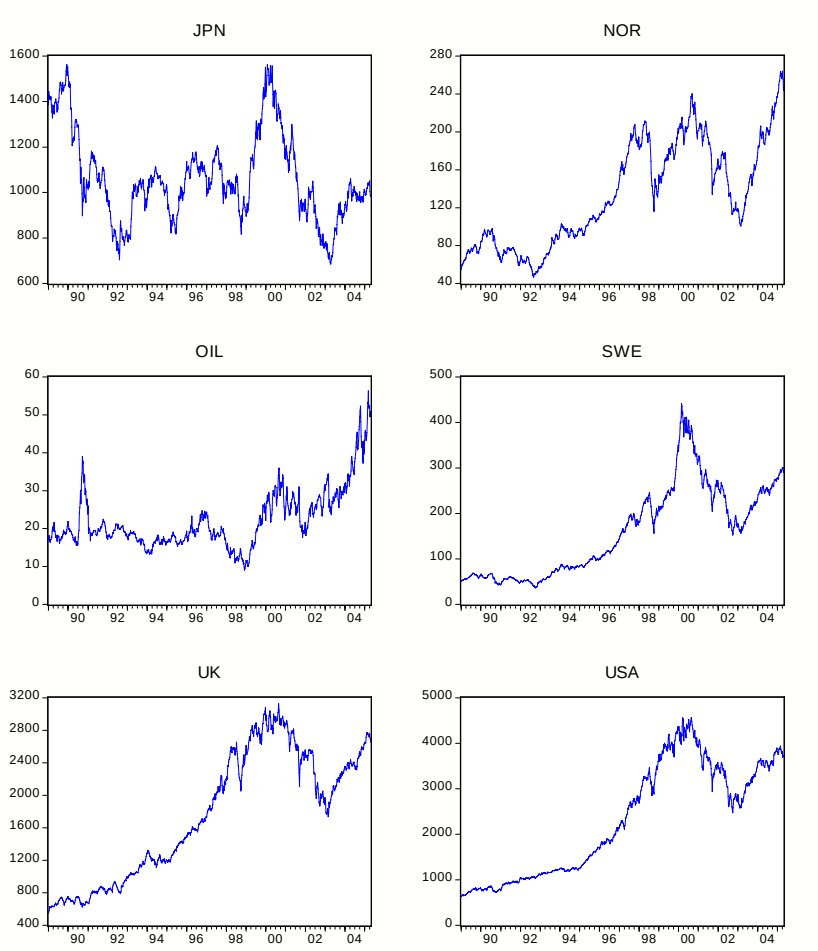
The percentage change or return over one data period, denoted r_{it}, is derived as one hundred times the log-difference in prices over the period, i.e.,

$$r_{it} = 100 \times \log \frac{P_{it}}{P_{i,t-1}}, \tag{1}$$

where P_{it} is the price level of market i at time t. Table 1 reports on summary statistics of the return data on all five stock indices and the oil price. All stock markets but Japan have had a positive average weekly return over the sample period. Standard deviations are centered around 2.5 percent except for the oil price, which has varied 5.21 percent. All data series display non-zero skewness and excess kurtosis, leading to highly significant Jarque-Bera statistics, which indicate that the returns are non-normally distributed. Moreover, results of the Ljung-Box Q test suggest that serial correlations exists in the Norwegian, the Swedish, and the U.S. stock return data. Both the Ljung-Box Q test for squared returns and the ARCH Lagrange multiplier test indicate strong presence of ARCH-structure in all data series.

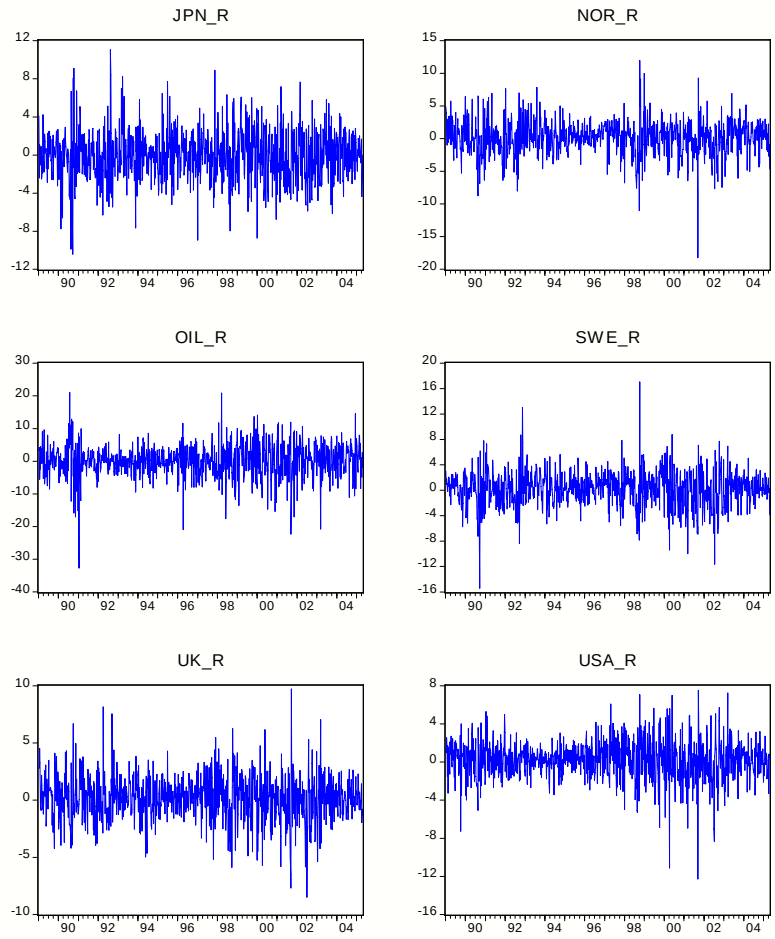
Figures 1 and 2 illustrate the data. Figure 1 plots the weekly index/price level of the six data series. Observe that the oil price was rather stable around \$20 during the 1990s apart from the spike in 1990-91 when the Gulf war commenced. Since the 1990s, the oil price level has shown more instability. The aggregate stock market indices have risen during the sample period, with the exception of Japan. Figure 2 graphs the weekly percentage returns of all data series derived according to (1). Notice that the stock return conditional volatilities are historically large, even during the 1990s. The return series display volatility persistence (clustering) in accordance with the previous statistical test results. It is, however, difficult to visually detect any comovements in conditional volatility between oil and stock markets. I leave this to statistical modeling and testing.

Figure 1: Weekly Indices of Five National Stock Markets and the Oil Price



The figure plots the historical development of five aggregate stock markets representing Japan, Norway, Sweden, the U.K., and the U.S., respectively; along with the price of Brent crude oil in 2005 U.S. dollars per barrel. The sample period covers week one of 1989 through week seventeen of 2005.

Figure 2: Weekly Returns of Five National Stock Markets and Changes in the Oil Price



The figure plots historical returns (%) of five aggregate stocks representing Japan, Norway, Sweden, the U.K., and the U.S., respectively; along with the price change of Brent crude oil. The sample period covers week two of 1989 through week seventeen of 2005.

3 Statistical Model

Consider a bivariate sequence of data $\{\mathbf{r}_t\}_{t=1}^{T}$ consisting of oil price changes and stock market returns. The following statistical model is employed:

$$\mathbf{r}_t = \boldsymbol{\mu} + \boldsymbol{\delta}\mathbf{r}_{t-1} + \boldsymbol{\pi}\mathbf{r}_{t-2} + \boldsymbol{\varepsilon}_t, \tag{2}$$

$$\boldsymbol{\varepsilon}_t = \mathbf{H}_t^{1/2}\mathbf{v}_t, \tag{3}$$

and

$$\mathbf{H}_t = \mathbf{C}'\mathbf{C} + \mathbf{A}'\boldsymbol{\varepsilon}_{t-1}\boldsymbol{\varepsilon}_{t-1}'\mathbf{A} + \mathbf{B}'\mathbf{H}_{t-1}\mathbf{B} + \mathbf{G}'\boldsymbol{\eta}_{t-1}\boldsymbol{\eta}_{t-1}'\mathbf{G}, \tag{4}$$

where $\boldsymbol{\varepsilon}_t$ is a 2×1 vector of residuals, $\mathbf{v}_t$ is a 2×1 vector of standardized (i.i.d.) residuals, $\mathbf{H}_t$ is the 2×2 conditional covariance matrix, $\boldsymbol{\eta}_t$ is a 2×1 asymmetric term (defined subsequently), and $\boldsymbol{\mu}$, $\boldsymbol{\delta}$, $\boldsymbol{\pi}$, $\mathbf{C}$, $\mathbf{A}$, $\mathbf{B}$, and $\mathbf{G}$ are model parameter matrices. The mean equation (2) is represented by a VAR(2) model. In this way, any existing serial correlation in the return series is removed, which is crucial since the parameter estimates of $\mathbf{H}_t$ would otherwise be biased. The conditional variance-covariance matrix of (4) is specified according to the ABEKK model of Kroner and Ng (1998). Notice that the structure consists of quadratic forms, which secures the positive definiteness of $\mathbf{H}_t$. The statistical model of (2)-(4) is referred to as the VAR(2)-ABEKK model.[8]

The ABEKK model includes an asymmetric term, $\boldsymbol{\eta}_t = (\eta_{1t}, \eta_{2t})'$, which elements are defined as: $\eta_{it} = \max[\varepsilon_{it}, 0]$, for oil price changes; and $\eta_{it} = \min[\varepsilon_{it}, 0]$, for stock returns. This specification of $\boldsymbol{\eta}_t$ emphasizes on the effects of positive oil shocks and negative stock returns. The latter emphasis is motivated by Glosten, Jagannathan, and Runkle (1993).

3.1 Parameter Restrictions

To ensure that stock prices have no impact on oil prices, which is economically justifiable following Hamilton (1985), some restrictions are imposed on the parameter matrices of (2) and (4).[9] Explicitly, the restricted VAR(2)-ABEKK model has the following structure:

$$r_{1t} = \mu_1 + \delta_{11}r_{1,t-1} + \pi_{11}r_{1,t-2} + \varepsilon_{1t}, \tag{5}$$

$$r_{2t} = \mu_2 + \delta_{21}r_{1,t-1} + \delta_{22}r_{2,t-1} + \pi_{21}r_{1,t-2} + \pi_{22}r_{2,t-2} + \varepsilon_{2t}, \tag{6}$$

[8] Bauwens, Laurent, and Rombouts (2006) survey the literature on MGARCH models.

[9] The restricted model is supported statistically as well, since the parameters that are restricted to zero display insignificant estimates following an unrestricted estimation.

and

$$\begin{pmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{pmatrix} = \begin{pmatrix} h_{11,t} & h_{12,t} \\ h_{12,t} & h_{22,t} \end{pmatrix}^{1/2} \begin{pmatrix} v_{1t} \\ v_{2t} \end{pmatrix}, \tag{7}$$

where

$$\begin{aligned} h_{11,t} &= c_{11}^2 + a_{11}^2\varepsilon_{1,t-1}^2 + b_{11}^2 h_{11,t-1}^2 + g_{11}^2\eta_{1,t-1}^2, & (8)\\ h_{12,t} &= c_{11}c_{12} + a_{11}a_{12}\varepsilon_{1,t-1}^2 + a_{11}a_{22}\varepsilon_{1,t-1}\varepsilon_{2,t-1} \\ &\quad + b_{11}b_{12}h_{11,t-1} + b_{11}b_{22}h_{12,t-1} \\ &\quad + g_{11}g_{12}\eta_{1,t-1}^2 + g_{11}g_{22}\eta_{1,t-1}\eta_{2,t-1}, & (9)\\ h_{22,t} &= c_{12}^2 + c_{22}^2 + a_{12}^2\varepsilon_{1,t-1}^2 + a_{22}^2\varepsilon_{2,t-1}^2 + 2a_{12}a_{22}\varepsilon_{1,t-1}\varepsilon_{2,t-1} \\ &\quad + b_{12}^2 h_{11,t-1} + b_{22}^2 h_{22,t-1} + 2b_{12}b_{22}h_{12,t-1} \\ &\quad + g_{12}^2\eta_{1,t-1}^2 + g_{22}^2\eta_{2,t-1}^2 + 2g_{12}g_{22}\eta_{1,t-1}\eta_{2,t-1}. & (10) \end{aligned}$$

In (5) and (6), r_{1t} (r_{2t}) represents the period t percentage change in oil (aggregate stock) prices according to (1). Stock returns do not affect oil price changes in equation (5), but oil price changes do affect stock returns, as (6) shows. Moreover, the conditional variance of oil price changes, $h_{11,t}$, is simply modeled by the univariate GJR(1,1) model of Glosten et al. (1993), while the conditional variance of stock returns, $h_{22,t}$, and the conditional covariance, $h_{12,t}$, are modeled with more complexity. The ABEKK model allows, for instance, the conditional variance of stock returns to depend on its own lagged conditional variance and lagged shocks, the lagged conditional variance and lagged shocks of oil price changes, as well as cross-terms. The parameter a_{12} in (10) captures the effect of an oil shock at $t-1$ on the conditional variance of stock returns at t, and b_{12} measures the impact of the oil price conditional variance on the one-period ahead conditional variance of stock returns. The parameters of the ABEKK specification do not represent such impacts directly however, since parameters are squared or cross-multiplied. This implies that the interpretation of individual parameter estimates is not straightforward. Nevertheless, the statistical significance of the parameter estimates can be investigated.

3.2 Estimation

The bivariate restricted VAR(2)-ABEKK model is estimated using the quasi maximum likelihood (QML) method of Bollerslev and Wooldridge (1992). Given T

observations of $\mathbf{r}_t = (r_{1t}, r_{2t})'$, the following optimization is considered:

$$\max_{\theta} \log L_T(\theta) = \sum_{t=1}^{T} l_t(\theta), \tag{11}$$

where L_T is the sample likelihood function, θ is a vector of parameters,

$$l_t(\theta) = \log(2\pi) - \log|\mathbf{H}_t| - \frac{1}{2}\boldsymbol{\varepsilon}_t'\mathbf{H}_t^{-1}\boldsymbol{\varepsilon}_t \tag{12}$$

is the conditional log-likelihood function for a bivariate normally distributed variable, and $\boldsymbol{\varepsilon}_t = (\varepsilon_{1t}, \varepsilon_{2t})'$ and $\text{vech}(\mathbf{H}_t) = (h_{11,t}, h_{12,t}, h_{22,t})'$ follow (7) and (8)-(10), respectively. QML robust standard errors of the parameter estimates are derived to account for the possibly false normality assumption.

To carry out the optimization of (11), the BFGS quasi-Newton method is applied using the Matlab programming language.[10] Since the parameter vector θ has a total of 20 parameters (see equations (5)-(10)), the optimization is quite intricate and sensitive to starting values. I use a number of simplex-algorithm iterations following an initial guess of parameter values.[11] This is found to help for convergence.

3.3 Tests of Model Fitness

To test the model's fitness, the obtained estimated standardized residuals $\hat{\mathbf{v}}_t = (\hat{v}_{1t}, \hat{v}_{2t})'$ are analyzed. These are derived as the inverse of the Cholesky decomposition of $\mathbf{H}_t$ times the estimated residual vector $\hat{\boldsymbol{\varepsilon}}_t$, in line with (3). The statistical model provides a good fit to the empirical data if a test of remaining serial correlation and ARCH-structure comes out insignificant. Two such tests are performed, namely the multivariate Ljung-Box Q test, and a bivariate test based on the generalized method of moments (GMM).

3.3.1 Multivariate Ljung-Box Q Test

The multivariate Ljung-Box Q (MLBQ) test of Hosking (1980) is a test of serial correlation.[12] Under the null that $\hat{\mathbf{v}}_t$ is independent of $\hat{\mathbf{v}}_{t-1}, ..., \hat{\mathbf{v}}_{t-K}$, where K is the maximum lag length, the test statistic

$$MLBQ = T(T+2)\sum_{j=1}^{K} \frac{1}{T-j} tr\left\{C_{0j}C_{00}^{-1}C_{0j}'C_{00}^{-1}\right\}, \tag{13}$$

[10] The unconstrained minimization routine *fminunc* is employed.
[11] The Matlab function *fminsearch* is employed.
[12] Box and Jenkins (1976) present the univariate Ljung-Box Q test.

where $C_{0j} = T^{-1}\sum_{t=j+1}^{T}\hat{\mathbf{v}}_t\hat{\mathbf{v}}'_{t-j}$, is derived.[13] Applying the test to the squared standardized residuals, $\hat{\mathbf{v}}_t^2$, the MLBQ test provides a test for ARCH-effects too, referred to as the MLBQ^2 test. The statistic in (13) is χ^2 distributed with $4(K-2)$ degrees of freedom. The lag length is arbitrarily set to $K = 8$, implying that serial correlation up to eight weeks is examined.

3.3.2 GMM Test

The GMM approach to testing the model fitness relies on a number of moment conditions. One advantage compared with the MLBQ test is that the GMM approach tests for serial correlation and ARCH-effects simultaneously. Under the null of a correctly specified model, $\{\hat{v}_{it}\}$, $\{\hat{v}_{it}^2 - 1\}$, and $\{\hat{v}_{1t}\hat{v}_{2t}\}$ should be serially uncorrelated. The following moment conditions should therefore hold:

$$
\begin{aligned}
E[\hat{v}_{it}\hat{v}_{i,t-k}] &= 0, \text{ for } i = 1, 2, && (14)\\
E[\hat{v}_{it}\hat{v}_{j,t-k}] &= 0, \text{ for } (i,j) = (1,2) \text{ and } (2,1), && (15)\\
E[(\hat{v}_{it}^2 - 1)(\hat{v}_{i,t-k}^2 - 1)] &= 0, \text{ for } i = 1, 2, && (16)\\
E[(\hat{v}_{1t}\hat{v}_{2t})(\hat{v}_{1,t-k}\hat{v}_{2,t-k})] &= 0, && (17)
\end{aligned}
$$

where $k = 1, 2, ..., K$. The model fitness is decided on by testing the seven moment conditions (14)-(17) jointly using GMM.[14] The test statistic is derived as

$$GMM = T \cdot g_T{}' {S_T}^{-1} g_T, \tag{18}$$

where g_T is a vector of sample counterparts to the moment conditions, and S_T is the corresponding sample variance-covariance matrix. The statistic (18) is χ^2 distributed with $7K$ degrees of freedom. Again, I set the lag length to $K = 8$.

Two simple simulation studies are conducted to determine the size of the two test of model fitness.[15] There is a tendency for the GMM test to reject a true null too often. This is however only a problem if one observes many rejections.

3.4 Testing for Volatility Spillover

Consider the statistical model's expression for the conditional stock return variance in (10). Oil price uncertainty transmits to stock volatility, $h_{22,t}$, through three channels; via the symmetric shock, $\varepsilon_{1,t-1}$, the asymmetric shock, $\eta_{1,t-1}$, or the conditional

[13] This presentation of the MLBQ test follows Hatemi-J (2004).

[14] Ng (2000) carries out a similar GMM approach to testing model fitness.

[15] The size of a statistical test equals the probability of rejecting a true null hypothesis.

oil price variance of the previous period, $h_{11,t-1}$. Thus volatility spillover is tested via the corresponding parameter estimates of a_{12}, g_{12}, and b_{12}. There is evidence of volatility spillover if a joint test of the three parameters being zero is rejected. Formally, the null hypothesis

$$H_0 : a_{12} = b_{12} = g_{12} = 0, \tag{19}$$

is tested by deriving both Wald and Likelihood ratio (LR) statistics. The Wald test uses the obtained estimates of a_{12}, g_{12}, and b_{12} along with the corresponding estimated variance-covarinace matrix, and a Wald statistic is derived in the usual way. The LR test compares the maximum likelihood of the unconstrained estimation with the one obtained when the constraint (19) is enforced.[16]

4 Empirical Results

This section presents the results of the statistical model estimation. The obtained parameter estimates are analyzed, and news impact surfaces of Kroner and Ng (1998) are presented. Such graphical illustrations show the impacts of an oil shock and a stock price shock on, e.g., the one-period ahead conditional stock price volatility, holding all past conditional variances and covariances constant at their unconditional averages.[17] In this way, the magnitude of the impact of an oil shock on conditional stock volatility is illustrated. Moreover, a second set of estimations is carried out, where oil prices a leaded one period, to test for within-the-week effects of volatility spillover.

4.1 Primary Estimations

Table 2 summarizes the bivariate restricted VAR(2)-ABEKK estimation results.[18] Panel A presents the conditional mean parameter estimates. The estimated conditional stock return intercepts, μ_2, are all positive and significantly different from zero at the five percent level except for Japan, where the estimated intercept equals -0.1047 and insignificant. Oil price changes have conditional mean equations with insignificant intercepts throughout. Evidence of stock return serial correlation is found for Norway, Sweden, and the U.S, as was previously suggested by the signif-

[16] To read more on the Wald and Likelihood ratio statistics, see, e.g., Hamilton (1994).

[17] The news impact surface is a direct multivariate extension of Engle and Ng's (1993) univariate news impact curve.

[18] Full estimation results including QML standard errors and p-values are presented in tables A.1-A.5 in the appendix.

Table 2: Restricted VAR(2)-ABEKK Estimation Results

	Japan	Norway	Sweden	U.K.	U.S
Panel A: Conditional mean estimates					
μ_1	0.0907	0.0699	0.0736	0.0771	0.0683
μ_2	-0.1047	0.1843*	0.2553*	0.1844*	0.2769*
δ_{11}	-0.0247	-0.0166	-0.0047	-0.0306	0.0061
δ_{21}	-0.0176	0.0103	-0.0009	-0.0067	-0.0156
δ_{22}	-0.0528	0.0719	0.0914*	-0.0178	-0.1377*
π_{11}	-0.0150	-0.0198	-0.0211	-0.0147	-0.0250
π_{21}	0.0156	-0.0132	-0.0196	-0.0028	-0.0382*
π_{22}	0.0082	0.1049*	0.0555	0.0441	0.0505
Panel B: Conditional variance-covariance estimates					
c_{11}	0.7938*	0.8428*	0.8599*	0.7871*	0.8425*
c_{12}	0.1182	0.7017*	0.6269*	-0.0434	0.1038
c_{22}	0.6603*	-0.0072	0.0001	0.2984*	-0.0001
a_{11}	0.3127*	-0.3529*	0.3637*	0.3338*	0.3470*
a_{12}	0.0049	-0.0367	-0.0462	-0.0388*	0.0003
a_{22}	0.1768*	0.1628	0.0841	0.0433	0.0919
b_{11}	0.9254*	-0.9184*	-0.9150*	0.9271*	-0.9172*
b_{12}	0.0145	-0.1489*	0.0001	0.0200*	0.0147
b_{22}	0.9136*	0.9140*	0.8971*	0.9417*	0.9731*
g_{11}	-0.2563*	0.1763	0.1627	-0.1681	0.2141
g_{12}	0.0908*	-0.0541	0.0774	0.0225	-0.0996*
g_{22}	-0.2980*	0.3303*	0.5295*	-0.3691*	-0.2394*
max L	-4539.24	-4493.88	-4524.26	-4270.38	-4280.92
Panel C: Tests of model fitness					
MLBQ	26.88	28.47	39.34	39.63	34.07
	(0.525)	(0.440)	(0.076)	(0.071)	(0.199)
MLBQ^2	38.12	31.05	23.57	25.62	29.56
	(0.096)	(0.315)	(0.704)	(0.594)	(0.385)
GMM	51.53	61.05	67.28	68.86	73.36
	(0.645)	(0.299)	(0.144)	(0.116)	(0.060)
Panel D: Tests of volatility spillover					
Wald	17.57*	26.97*	12.07*	15.68*	67.95*
	(<0.001)	(<0.001)	(0.007)	(0.001)	(<0.001)
LR	10.50*	21.52*	4.81	10.81*	15.04*
	(0.015)	(<0.001)	(0.186)	(0.013)	(0.002)

The table summarizes the bivariate restricted VAR(2)-ABEKK estimation results. Variable 1 (2) refers to oil (stocks). QML standard errors are used to determine parameter-estimate significance. p-values are in parentheses. * indicates significance at five percent level.

icant LBQ statistics of table 1. The Sweden and U.S. estimations give significant estimates of δ_{22}, which indicates serial correlation over one period, and the Norway estimation results in a significant estimate of π_{22}, suggesting a correlation over two periods. Furthermore, the estimate of π_{21} is negative and significant for the U.S. alone, implying that positive oil shocks have a significant negative impact on one-week ahead U.S. stock returns. The result for the U.S. supports previous work by Jones and Kaul (1996) and Sadorsky (1999), although they use quarterly and monthly data, respectively.

The stock return serial correlations are successfully removed by the VAR(2) model, as the insignificant MLBQ statistics in panel C show. Considering, also, the insignificant MLBQ^2 and GMM statistics in the panel, the statistical model provides an overall good fit to the data. Panel B reports on estimates of the conditional variance-covariance parameters. Notice that the a_{11} and b_{11} parameters of conditional oil price volatility are significant throughout, but that the parameter representing asymmetric oil price volatility, g_{11}, is only significant in the Japan estimation. Consequently, oil price volatility is conditionally heteroskedastic, however without displaying asymmetric effects to oil price increases and decreases in general.

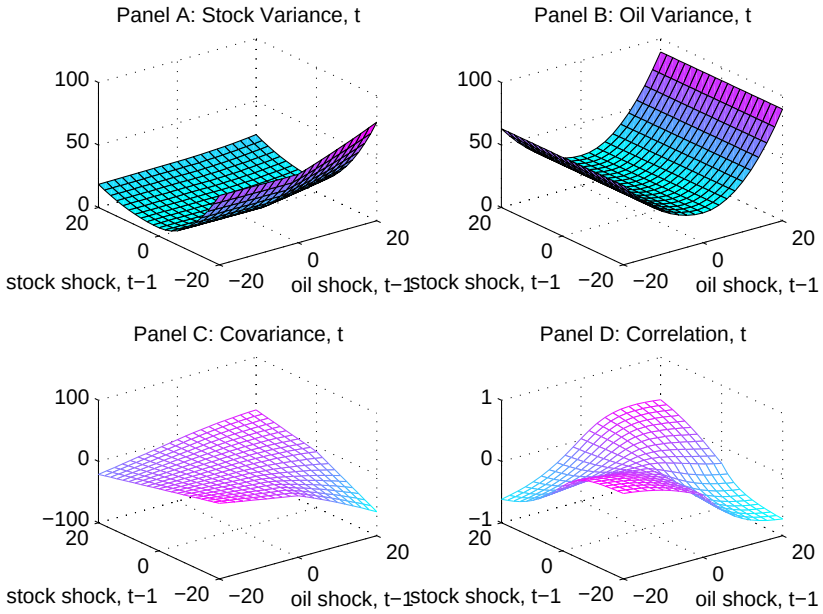
Evidence of time-persistence in conditional stock market volatility is reported on by the significant estimates of b_{22} across all the five regressions. Rarely any of the estimated symmetric shock parameters, a_{22}, come out significant, while the estimates of the asymmetric terms, g_{22}, are significant across every stock market. Thus the results support the finding of Glosten et al. (1993), and many others, who present empirical evidence of asymmetric stock market volatility, i.e., negative stock price shocks cause for larger swings in the next period's conditional variance than positive ones do.

The parameters of volatility spillover from oil price changes to stock returns, a_{12}, b_{12}, and g_{12}, are significant for some economies and insignificant for others. Oil price shocks have significant symmetric effects on only the U.K. conditional stock price volatility. Indications that the Japanese and U.S. aggregate stock markets respond asymmetrically to oil shocks are shown via the respective significant estimates of g_{12}. Different from the other economies, the conditional stock price volatilities of Sweden and Norway display no significant signs of responses to oil shocks. For Norway, evidence of time-persistence between the conditional oil price volatility and the one-period ahead conditional stock volatility, measured by b_{12}, is presented however. This is also the case for the U.K. stock market.

Although the parameters of volatility spillover are not significant overall, the tests of volatility spillover, reported on in panel D of table 2, show significant evidence of

such across all national stock markets. The Wald and LR statistics derived under the null in (19) are greater than ten and significant across all countries but Sweden, where the LR statistic is insignificant at 4.81. The Wald statistic for Sweden is significant though. Hence, the results show strong evidence of volatility spillover for Japan, Norway, the U.K., and the U.S., but only weak evidence for Sweden. Moreover, the significant g_{12} estimates of Japan and the U.S. suggest that oil prices have asymmetric volatility spillover effects on the stock markets of these economies.

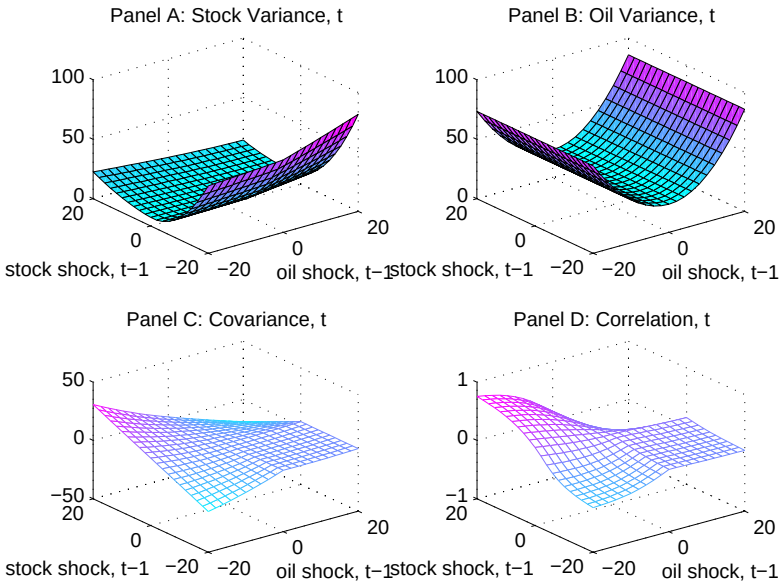
Figure 3: News Impact Surfaces for Japan



The figure shows the news impact of shocks at time $t-1$ on the variances, covariance, and correlation at time t using Japanese data.

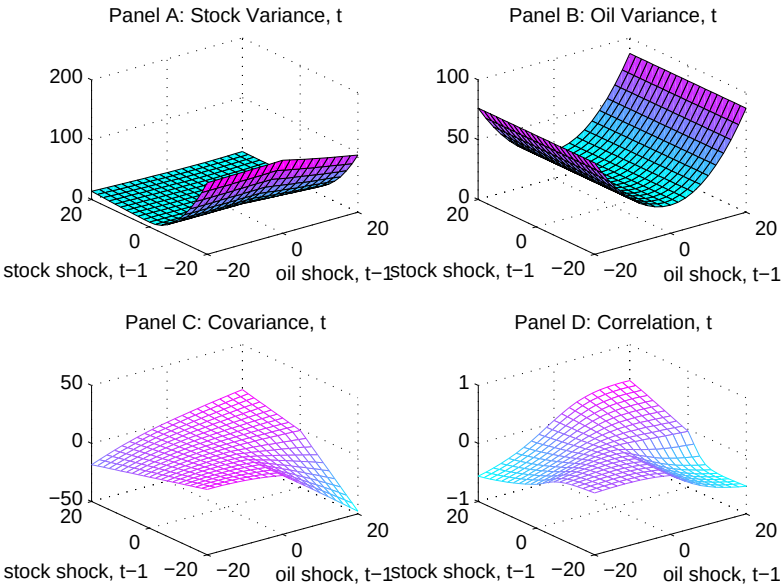
Table 2 presents evidence of volatility spillovers but gives no information about their size. How large impacts do the oil price volatility spillovers have on the aggregate stock markets? Figures 3-7 illustrate news impact surfaces for each respective estimation. The graphs show the implied conditional variances (panels A and B), the implied conditional covariances (panels C), and the implied conditional correlations (panels D) following last period's shocks, with all previous conditional variances and covariances held constant at their unconditional averages. Specifically, panels A of each figure present the impact of oil shocks and stock shocks on the one-period ahead conditional stock variances. The figures show that, although significant spillovers were previously presented, the impacts of oil shocks on stock volatility are quite

Figure 4: News Impact Surfaces for Norway



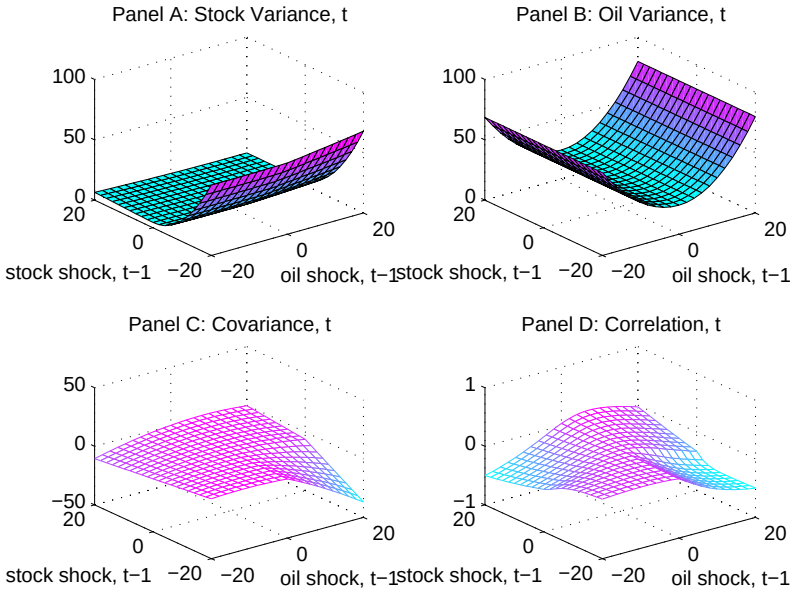
The figure shows the news impact of shocks at time $t-1$ on the variances, covariance, and correlation at time t using Norwegian data.

Figure 5: News Impact Surfaces for Sweden



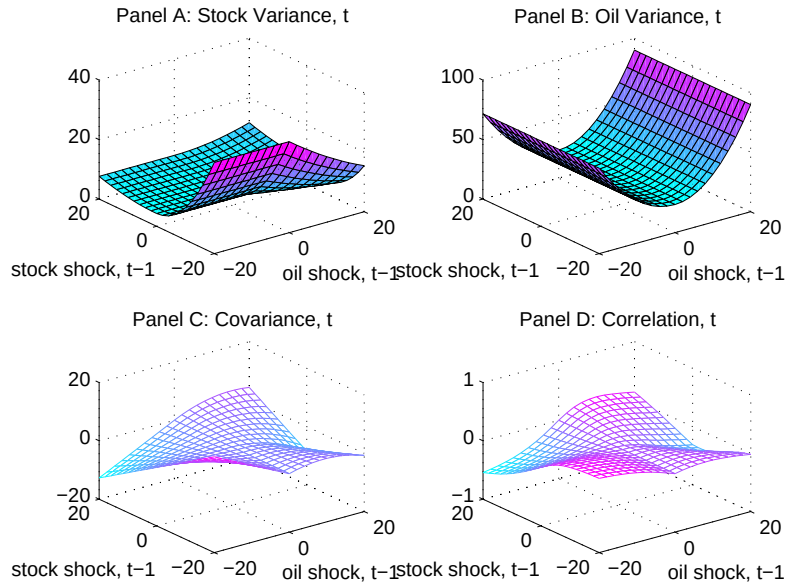
The figure shows the news impact of shocks at time $t-1$ on the variances, covariance, and correlation at time t using Swedish data.

Figure 6: News Impact Surfaces for the U.K.



The figure shows the news impact of shocks at time $t-1$ on the variances, covariance, and correlation at time t using U.K. data.

Figure 7: News Impact Surfaces for the U.S.



The figure shows the news impact of shocks at time $t-1$ on the variances, covariance, and correlation at time t using U.S. data.

minor in comparison to the effect that stock returns' own shocks have on volatility. For example, studying panel A of figure 3, negative shocks to the stock price cause the stock volatility to increase quite dramatically. For oil shocks however, the news impact surface shows that a ten percent decrease in the oil price has barely any effect on the Japanese stock price volatility. A ten percent increase in the oil price has small effects on the Japanese aggregate stock variance, illustrating the suggested asymmetric volatility spillover. For the U.S., where an asymmetry was suggested as well, panel A of figure 7 indicates that positive oil shocks *decrease* the conditional stock variance. This result is strange, since one expects positive oil shocks to increase, and not decrease, stock volatility.

Panels B of figures 3-7 show that, because of the ABEKK model parameter restrictions oil price volatility is only affected by its own shocks. There is no clear indication of asymmtric responses to positive and negative oil shocks, confirming the previous results of table 2 except, perhaps, for the Japan estimation, where the g_{11} estimate was indeed significant. Moreover, panels C and D display the news impacts on the conditional covariances and the conditional correlations. These illustrations show how oil shocks and stock shocks affect the one-period ahead conditional covariance and correlation, respectively, between stock price returns and oil price changes. Negative oil shocks and positive stock shocks cause for a clearly positive next-period correlation in the Norway estimation, as panel D of figure 4 shows. However, the relation is the opposite for the rest of the analyzed economies, where negative oil shocks and positive stock shocks cause for a negative next-period correlation.

4.2 Second Set of Estimations with Leaded Oil Price

The previous subsection presents strong evidence of volatility spillover from oil price changes to most of the analyzed aggregate stock markets. Since weekly data is considered, oil price volatility spills over to stock markets from one week to the next. One could, however, argue that the flow of oil price uncertainty is faster than a week. Do stock markets actually move "simultaneously" with the uncertainty of oil prices, i.e., within the same week?[19] To answer this question, a second set of estimations is considered where oil prices are leaded one period. Such a modification alters the presentation of the statistical model in (5)-(10), which becomes

$$r_{1t} = \mu_1 + \delta_{11} r_{1,t-1} + \pi_{11} r_{1,t-2} + \varepsilon_{1t}, \tag{20}$$

$$r_{2t} = \mu_2 + \delta_{21} r_{1t} + \delta_{22} r_{2,t-1} + \pi_{21} r_{1,t-1} + \pi_{22} r_{2,t-2} + \varepsilon_{2t}, \tag{21}$$

[19] Within-the-week volatility spillovers are henceforth referred to as simultaneous or contemporaneous ones.

and

$$\begin{pmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{pmatrix} = \begin{pmatrix} h_{11,t} & h_{12,t} \\ h_{12,t} & h_{22,t} \end{pmatrix}^{1/2} \begin{pmatrix} v_{1t} \\ v_{2t} \end{pmatrix}, \tag{22}$$

where

$$\begin{aligned} h_{11,t} &= c_{11}^2 + a_{11}^2\varepsilon_{1,t-1}^2 + b_{11}^2 h_{11,t-1}^2 + g_{11}^2\eta_{1,t-1}^2, && (23) \\ h_{12,t} &= c_{11}c_{12} + a_{11}a_{12}\varepsilon_{1t}^2 + a_{11}a_{22}\varepsilon_{1t}\varepsilon_{2,t-1} \\ &\quad + b_{11}b_{12}h_{11,t} + b_{11}b_{22}h_{12,t-1} \\ &\quad + g_{11}g_{12}\eta_{1t}^2 + g_{11}g_{22}\eta_{1t}\eta_{2,t-1}, && (24) \\ h_{22,t} &= c_{12}^2 + c_{22}^2 + a_{12}^2\varepsilon_{1t}^2 + a_{22}^2\varepsilon_{2,t-1}^2 + 2a_{12}a_{22}\varepsilon_{1t}\varepsilon_{2,t-1} \\ &\quad + b_{12}^2 h_{11,t} + b_{22}^2 h_{22,t-1} + 2b_{12}b_{22}h_{12,t-1} \\ &\quad + g_{12}^2\eta_{1t}^2 + g_{22}^2\eta_{2,t-1}^2 + 2g_{12}g_{22}\eta_{1t}\eta_{2,t-1}, && (25) \end{aligned}$$

where r_{1t} (r_{2t}) represents conditional oil price changes (stock returns).

Notice the slight differences of model (20)-(25) compared with the previous one of (5)-(10). Simultaneous effects of oil shocks onto conditional stock returns (21) and conditional stock volatility (25) are now considered.

Table 3 summarizes the bivariate restricted VAR(2)-ABEKK model estimation results when oil prices are leaded one week. Panel A reports on the mean equation parameter estimates, where evidence of serial correlation in Norwegian, Swedish, and U.S. stock returns is shown, just like in the previous estimations. Moreover, evidence of positive mean spillover from oil prices to the Norwegian stock index is implied by the significant estimate of δ_{21}. This suggests that the Norwegian aggregate stock market responds positively to a contemporaneous oil shock.

Panel B of table 3 presents the conditional variance-covariance parameter estimates, and panel D reports on the tests of volatility spillover. The most striking differences compared with the estimation results without leading the oil price is that the two tests of volatility spillover now come out unanimously significant for the estimation with the U.S. stock market only. The previous evidence of volatility spillovers for the other stock markets are no longer present, which suggests that only U.S. stocks vary contemporaneously with oil price variations. However, panel C presents a significant GMM statistic of overall model fitness for the U.S. estimation, rejecting the null of a good model fit, which weakens the interpretation of the significant volatility spillover. Generally, there is no empirical evidence of simultaneous volatility spillovers from oil prices to stock markets, making the result that volatility spills over from one week to the next more robust.

Table 3: Restricted VAR(2)-ABEKK Leaded Oil Price Estimation Results

	Japan	Norway	Sweden	U.K.	U.S
Panel A: Conditional mean estimates					
μ_1	0.0568	0.1273	0.0389	0.0992	0.0704
μ_2	-0.0882	0.1737*	0.2585*	0.1760*	0.2312*
δ_{11}	-0.0071	-0.0084	-0.0199	-0.0187	-0.0164
δ_{21}	0.0289	0.0927*	0.0034	0.0032	-0.0135
δ_{22}	-0.0408	0.0634	0.0892*	-0.0190	-0.1354*
π_{11}	-0.0170	-0.0244	-0.0243	-0.0189	-0.0298
π_{21}	-0.0144	0.0097	-0.0001	0.0006	-0.0084
π_{22}	0.0291	0.0980*	0.0519	0.0387	0.0730*
Panel B: Conditional variance-covariance estimates					
c_{11}	0.8163*	0.8879*	0.9004*	0.8056*	0.7905*
c_{12}	-0.0629	-0.0001	0.1534	-0.0991	-0.1314
c_{22}	0.7540*	0.7283*	0.5707*	-0.3684*	-0.2155
a_{11}	0.3514*	0.3363*	0.3773*	0.3497*	0.3634*
a_{12}	0.0295	0.0447	-0.0181	-0.0321	-0.0311
a_{22}	0.0830	-0.0983	-0.1373	0.0288	-0.0425
b_{11}	0.9198*	0.9164*	0.9127*	0.9208*	0.9226*
b_{12}	-0.0006	-0.0139	0.0042	0.0117	0.0191
b_{22}	0.9079*	0.9017*	0.9049*	0.9373*	0.9500*
g_{11}	-0.1800	0.2379*	-0.0933	-0.1806	0.0902
g_{12}	0.1300	-0.0485	0.0384	0.0041	-0.0511*
g_{22}	0.4359*	-0.4279*	-0.4534*	0.3934*	0.3204*
max L	-4545.64	-4486.89	-4521.09	-4270.87	-4285.27
Panel C: Tests of model fitness					
MLBQ	23.98	27.38	43.23*	36.57	47.39*
	(0.683)	(0.498)	(0.033)	(0.129)	(0.012)
MLBQ^2	37.81	41.35*	28.32	23.80	30.62
	(0.102)	(0.050)	(0.448)	(0.692)	(0.334)
GMM	58.05	59.20	79.01*	63.59	75.23*
	(0.400)	(0.360)	(0.023)	(0.227)	(0.044)
Panel D: Tests of volatility spillover					
Wald	10.62*	4.74	3.67	4.09	11.98*
	(0.014)	(0.192)	(0.300)	(0.251)	(0.008)
LR	1.95	4.03	3.51	3.55	8.25*
	(0.584)	(0.258)	(0.320)	(0.314)	(0.041)

The table summarizes the bivariate restricted VAR(2)-ABEKK model estimation results when oil price changes are leaded one period. Variable 1 (2) refers to oil (stocks). QML standard errors are used to determine parameter-estimate significance. p-values are in parentheses. * indicates significance at five percent level.

5 Conclusions

The paper conducts an empirical investigation of volatility spillover from oil prices to stock markets. The statistical model includes a parameterization of the conditional variance-covariance of oil price changes and stock returns, specifically the asymmetric BEKK model. Parameter restrictions are imposed so that stock returns cannot affect oil prices. Aggregate stock market data representing Japan, Norway, Sweden, the U.K., and the U.S. are used. Over the sample period from week one of 1989 to week seventeen of 2005, strong evidence of volatility spillover is found for Japan, Norway, the U.K., and the U.S. Weak evidence of volatility spillover is found for Sweden. Although results of significant volatility spillovers are obtained, news impact surfaces display small quantative implications. The stock market's own shocks, which are related to other factors of uncertainty than the oil price, are more prominent than the effects of oil shocks.

The paper also examines whether volatility spillovers occur simulateneously, i.e., within-the-week instead of from one week to the next, as in the primary examination. To do so, the oil price is leaded one week, and a second set of estimations is carried out. However, no strong evidence of contemporanous volatility spillovers are found. In all, the paper improves our knowledge of how stock markets link to oil prices.

References

Basher, S. and P. Sadorsky (2004), "Oil price risk and emerging stock markets", Working paper, WUSTL archive.

Bauwens, L., S. Laurent, and J. Rombouts (2006), "Multivariate GARCH models: A survey", *Journal of Applied Econometrics* 21, 1, 79-109.

Bollerslev, T., R. Engle, and J. Wooldridge (1988), "A capital asset pricing model with time-varying covariances", *Journal of Political Economy* 96, 1, 116-31.

Bollerslev, T. and J. Wooldridge (1992), "Quasi-maximum likelihood estimation and inference in dynamic models with time-varying covariances", *Econometric Reviews* 11, 2, 143-72.

Box, G. and G. Jenkins (1976), *Time Series Analysis: Forecasting and Control*, rev. ed., Holden-Day, San Francisco.

Engle, R. (1982), "Autoregressive conditional heteroskedasticity with estimates of the variances of United Kingdom inflation", *Econometrica* 50, 987-1007.

Engle, R. and K. Kroner (1995), "Multivariate simultaneous generalized ARCH", *Econometric Theory* 11, 122-50.

Engle, R. and V. Ng (1993), "Measuring and testing the impact of news on volatility", *Journal of Finance* 48, 1749-78.

Glosten, L., R. Jagannathan, and D. Runkle (1993), "Relationship between the expected value and the volatility of the nominal excess return on stocks", *Journal of Finance* 48, 1779-1801.

Hamilton, J. (1983), "Oil and the macroeconomy since World War II", *Journal of Political Economy* 91, 228-48.

Hamilton, J. (1985), "Historical causes of postwar oil shocks and recessions", *Energy Journal* 6, 97-116.

Hamilton, J. (1994), *Time Series Analysis*, Princeton University Press, Princeton, New Jersey.

Hatemi-J, A. (2004), "Multivariate tests for autocorrelation in the stable and unstable VAR models", *Economic Modelling* 21, 4, 661-83.

Hosking, J. (1980), "The multivariate portmanteau statistic", *Journal of American Statistical Association* 75, 371, 602-8.

Huang, B.-N., M. Hwang, and H.-P. Peng (2005), "The asymmetry of the impact

of oil shocks on economic activities: An application of the multivariate threshold model, *Energy Economics* 27, 455-76.

Huang, R., R. Masulis, and H. Stoll (1996), "Energy shocks and financial markets", *Journal of Futures Markets* 16, 1, 1-27.

Jones, C. and G. Kaul (1996), "Oil and the stock markets", *Journal of Finance* 51, 2, 463-91.

Karolyi, G. (1995), "A multivariate GARCH model of international transmission of stock returns and volatility: The case of the United States and Canada", *Journal of Business and Economic Statistics* 13, 11-25.

Kearney, C. and A. Patton (2000), "Multivariate GARCH modelling of exchange rate volatility transmission in the European Monetary System", *Financial Review* 41, 29-48.

King, M., E. Sentana, and S. Wadhwani (1994), "Volatility and links between national stock markets", *Econometrica* 62, 4, 901-33.

Kroner, K. and V. Ng (1998), "Modelling asymmetric comovements of asset returns", *Review of Financial Studies* 11, 4, 817-44.

Mork, K. (1994), "Business cycles and the oil market (special issue)", *Energy Journal* 15, 15-37.

Mork, K., Ø. Olsen, and H. Mysen (1994), "Macroeconomic responses to oil price increases and decreases in seven OECD countries", *Energy Journal* 15, 4, 19-35.

Ng, A. (2000), "Volatility spillover effects from Japan and the U.S. to the Pacific-Basin", *Journal of International Money and Finance* 19, 207-33.

Officer, R. (1973), "The variability of the market factor of New York Stock Exchange", *Journal of Business* 46, 434-53.

Rogoff, K. (2006), "Oil and the global economy", Manuscript, Harvard University.

Sadorsky, P. (1999), "Oil price shocks and stock market activity", *Energy Economics* 21, 5, 449-69.

Sadorsky, P. (2003), "The macroeconomic determinants of technology stock price volatility", *Review of Financial Economics* 12, 191-205.

Schwert, G. (1989), "Why does stock market volatility change over time?", *Journal of Finance* 44, 5, 1115-53.

Vaitheeswaran, V. (2005), "Oil in troubled waters", *Economist*, April 30th.

Appendix

Table A.1: Restricted VAR(2)-ABEKK Estimation Results for Japan

	Est	QML S.E.	p-value
μ_1	0.0907	0.1565	0.5626
μ_2	-0.1047	0.0860	0.2234
δ_{11}	-0.0247	0.0388	0.5243
δ_{21}	-0.0176	0.0163	0.2802
δ_{22}	-0.0528	0.0379	0.1635
π_{11}	-0.0150	0.0348	0.6667
π_{21}	0.0156	0.0160	0.3292
π_{22}	0.0082	0.0333	0.8060
c_{11}	0.7938*	0.1888	<0.001
c_{12}	0.1182	0.1513	0.4347
c_{22}	0.6603*	0.1729	<0.001
a_{11}	0.3127*	0.0807	<0.001
a_{12}	0.0049	0.0209	0.8154
a_{22}	0.1768*	0.0519	<0.001
b_{11}	0.9254*	0.0228	<0.001
b_{12}	0.0145	0.0076	0.0564
b_{22}	0.9136*	0.0260	<0.001
g_{11}	-0.2563*	0.0676	<0.001
g_{12}	0.0908*	0.0255	<0.001
g_{22}	-0.2980*	0.0573	<0.001
max L	-4539.24		

The table reports on bivariate restricted VAR(2)-ABEKK estimation results using oil price changes and Japanese aggregate stock returns. QML standard errors and p-values are presented. * indicates significance at five percent level.

Table A.2: Restricted VAR(2)-ABEKK Estimation Results for Norway

	Est	QML S.E.	p-value
μ_1	0.0699	0.0988	0.4798
μ_2	0.1843*	0.0826	0.0259
δ_{11}	-0.0166	0.0364	0.6491
δ_{21}	0.0103	0.0166	0.5353
δ_{22}	0.0719	0.0375	0.0554
π_{11}	-0.0198	0.0221	0.3716
π_{21}	-0.0132	0.0151	0.3816
π_{22}	0.1049*	0.0350	0.0028
c_{11}	0.8428*	0.2032	<0.001
c_{12}	0.7017*	0.1809	<0.001
c_{22}	-0.0072	0.1191	0.9519
a_{11}	-0.3529*	0.0997	<0.001
a_{12}	-0.0367	0.0309	0.2341
a_{22}	0.1628	0.0944	0.0850
b_{11}	-0.9184*	0.0240	<0.001
b_{12}	-0.1489*	0.0356	<0.001
b_{22}	0.9140*	0.0299	<0.001
g_{11}	0.1763	0.2020	0.3829
g_{12}	-0.0541	0.0286	0.0588
g_{22}	0.3303*	0.0688	<0.001
max L	-4493.88		

The table reports on bivariate restricted VAR(2)-ABEKK estimation results using oil price changes and Norwegian aggregate stock returns. QML standard errors and p-values are presented. * indicates significance at five percent level.

Table A.3: Restricted VAR(2)-ABEKK Estimation Results for Sweden

	Est	QML S.E.	p-value
μ_1	0.0736	0.1731	0.6708
μ_2	0.2553*	0.0874	0.0036
δ_{11}	-0.0047	0.0427	0.9122
δ_{21}	-0.0009	0.0170	0.9562
δ_{22}	0.0914*	0.0379	0.0161
π_{11}	-0.0211	0.0350	0.5472
π_{21}	-0.0196	0.0150	0.1937
π_{22}	0.0555	0.0363	0.1261
c_{11}	0.8599*	0.2066	<0.001
c_{12}	0.6269*	0.0732	<0.001
c_{22}	0.0001	0.0030	0.9867
a_{11}	0.3637*	0.0783	<0.001
a_{12}	-0.0462	0.0262	0.0789
a_{22}	0.0841	0.1179	0.4759
b_{11}	-0.9150*	0.0222	<0.001
b_{12}	0.0001	0.0342	0.9992
b_{22}	0.8971*	0.0145	<0.001
g_{11}	0.1627	0.1803	0.3671
g_{12}	0.0774	0.0420	0.0657
g_{22}	0.5295*	0.0446	<0.001
max L	-4524.26		

The table reports on bivariate restricted VAR(2)-ABEKK estimation results using oil price changes and Swedish aggregate stock returns. QML standard errors and p-values are presented. * indicates significance at five percent level.

Table A.4: Restricted VAR(2)-ABEKK Estimation Results for the U.K.

	Est	QML S.E.	p-value
μ_1	0.0771	0.1658	0.6420
μ_2	0.1844*	0.0648	0.0045
δ_{11}	-0.0306	0.0403	0.4479
δ_{21}	-0.0067	0.0131	0.6071
δ_{22}	-0.0178	0.0356	0.6178
π_{11}	-0.0147	0.0354	0.6779
π_{21}	-0.0028	0.0117	0.8144
π_{22}	0.0441	0.0341	0.1964
c_{11}	0.7871*	0.2101	<0.001
c_{12}	-0.0434	0.0661	0.5112
c_{22}	0.2984*	0.0954	0.0018
a_{11}	0.3338*	0.1015	0.0010
a_{12}	-0.0388*	0.0179	0.0303
a_{22}	0.0433	0.0527	0.4116
b_{11}	0.9271*	0.0251	<0.001
b_{12}	0.0200*	0.0052	<0.001
b_{22}	0.9417*	0.0163	<0.001
g_{11}	-0.1681	0.1787	0.3471
g_{12}	0.0225	0.0311	0.4691
g_{22}	-0.3691*	0.0589	<0.001
max L	-4270.38		

The table reports on bivariate restricted VAR(2)-ABEKK estimation results using oil price changes and U.K. aggregate stock returns. QML standard errors and p-values are presented. * indicates significance at five percent level.

Table A.5: Restricted VAR(2)-ABEKK Estimation Results for the U.S.

	Est	QML S.E.	p-value
μ_1	0.0683	0.1556	0.6608
μ_2	0.2769*	0.0638	<0.001
δ_{11}	0.0061	0.0394	0.8766
δ_{21}	-0.0156	0.0134	0.2761
δ_{22}	-0.1377*	0.0377	<0.001
π_{11}	-0.0250	0.0360	0.4864
π_{21}	-0.0382*	0.0136	0.0050
π_{22}	0.0505	0.0359	0.1603
c_{11}	0.8425*	0.1806	<0.001
c_{12}	0.1038	0.0723	0.1516
c_{22}	-0.0001	0.0013	0.9948
a_{11}	0.3470*	0.0750	<0.001
a_{12}	0.0003	0.0197	0.9866
a_{22}	0.0919	0.0563	0.1026
b_{11}	-0.9172*	0.0204	<0.001
b_{12}	0.0147	0.0288	0.6084
b_{22}	0.9731*	0.0081	<0.001
g_{11}	0.2141	0.1210	0.0722
g_{12}	-0.0996*	0.0149	<0.001
g_{22}	-0.2394*	0.0667	<0.001
max L	-4280.92		

The table reports on bivariate restricted VAR(2)-ABEKK estimation results using oil price changes and U.S. aggregate stock returns. QML standard errors and p-values are presented. * indicates significance at five percent level.

WORKING PAPERS*
Editor: Nils Gottfries

2005:16 Pär Holmberg, Asymmetric Supply Function Equilibrium with Constant Marginal Costs. 27 pp.

2005:17 Pär Holmberg: Comparing Supply Function Equilibria of Pay-as-Bid and Uniform-Price Auctions. 25 pp.

2005:18 Anders Forslund, Nils Gottfries and Andreas Westermark: Real and Nominal Wage Adjustment in Open Economies. 49 pp.

2005:19 Lennart Berg and Tommy Berger, The Q Theory and the Swedish Housing Market – An Empirical Test. 16 pp.

2005:20 Matz Dahlberg and Magnus Gustavsson, Inequality and Crime: Separating the Effects of Permanent and Transitory Income. 27 pp.

2005:21 Jenny Nykvist, Entrepreneurship and Liquidity Constraints: Evidence from Sweden. 29 pp.

2005:22 Per Engström, Bertil Holmlund and Jenny Nykvist: Worker Absenteeism in Search Equilibrium. 35pp.

2005:23 Peter Hästö and Pär Holmberg, Some inequalities related to the analysis of electricity auctions. 7pp.

2006:1 Jie Chen, The Dynamics of Housing Allowance Claims in Sweden: A discrete-time hazard analysis. 37pp.

2006:2 Fredrik Johansson and Anders Klevmarken: Explaining the size and nature of response in a survey on health status and economic standard. 25pp.

2006:3 Magnus Gustavsson and Henrik Jordahl, Inequality and Trust: Some Inequalities are More Harmful than Others. 29pp.

2006:4 N. Anders Klevmarken, The Distribution of Wealth in Sweden: Trends and Driving factors. 20pp.

2006:5 Erica Lindahl and Andreas Westermark: Soft Budget Constraints as a Risk Sharing Arrangement in an Economic Federation. 22pp.

2006:6 Jonas Björnerstedt and Andreas Westermark: Bargaining and Strategic Discrimination. 36pp.

2006:7 Mikael Carlsson, Stefan Eriksson and Nils Gottfries: Testing Theories of Job Creation: Does Supply Create Its Own Demand? 23pp.

* A list of papers in this series from earlier years will be sent on request by the department.

2006:8 Annika Alexius and Erik Post, Cointegration and the stabilizing role of exchange rates. 33pp.

2006:9 David Kjellberg, Measuring Expectations. 46pp.

2006:10 Nikolay Angelov, Modellig firm mergers as a roommate problem. 21pp.

2006:11 Nikolay Angelov, Structural breaks in iron-ore prices: The impact of the 1973 oil crisis. 41pp.

2006:12 Per Engström and Bertil Holmlund, Tax Evasion and Self-Employment in a High-Tax Country: Evidence from Sweden. 16pp.

2006:13 Matias Eklöf and Daniel Hallberg, Estimating retirement behavior with special early retirement offers. 38pp.

2006:14 Daniel Hallberg, Cross-national differences in income poverty among Europe's 50+. 24pp.

2006:15 Magnus Gustavsson and Pär Österholm, Does Unemployment Hysteresis Equal Employment Hysteresis? 27pp.

2006:16 Jie Chen, Housing Wealth and Aggregate Consumption in Sweden. 52pp.

2006:17 Bertil Holmlund, Quian Liu and Oskar Nordström Skans, Mind the Gap? Estimating the Effects of Postponing Higher Education. 33pp.

2006:18 Oskar Nordström Skans, Per-Anders Edin and Bertil Holmlund, Wage Dispersion Between and Within Plants: Sweden 1985-2000. 57pp.

2006:19 Tobias Lindhe and Jan Södersten, The Equity Trap, the Cost of Capital and the Firm´s Growth Path. 20pp.

2006:20 Annika Alexius and Peter Welz, Can a time-varying equilibrium real interest rate explain the excess sensitivity puzzle? 27pp.

2006:21 Erik Post, Foreign exchange market interventions as monetary policy. 34pp.

2006:22 Karin Edmark and Hanna Ågren, Identifying Strategic Interactions in Swedish Local Income Tax Policies. 36pp.

2006:23 Martin Ågren, Does Oil Price Uncertainty Transmit to Stock Markets? 29pp.

See also working papers published by the Office of Labour Market Policy Evaluation http://www.ifau.se/

ISSN 1653-6975