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The effect of oil price on industrial production and on stock returns

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Abstract

This paper analyzes the relationship between oil price shocks and the industrial production and between oil price shocks and the stock returns. The objective is to study which relationship is stronger or which variables reacts more rapidly to changes in oil price. We develop a Markov switching model assuming that there exits a latent variable

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(the state of the economy) which determines the mean of industrial production and the volatility of stock returns. The results show that raises in oil price affects in a negative and statistically significant way to stock returns and to industrial production, but the effect on stock returns is stronger than on industrial production.

1 Introduction

A large body of research suggests that oil price variations have strong consequences on economic activity. Oil price increase is considered bad news in oil importing countries. An increase in oil price leads to a rise in production costs, because oil is a basic input in the production process. Moreover, oil price increases have a negative effect on investment by increasing firms' costs.

There are two distinguishing features of oil in the post war world economy. The first one is that oil is a major resource that has been used around the world. Second, oil price hikes in the post war era appear to be dominated by shocks exogenous to the rest of the economy, specifically by strike activity and coal prices. Hamilton (1983) studies the oil price changes in US and concludes that "... derived from events which truly were exogenous with respect to the American economy, such that the nationalization of Iranian assets, the Suez crisis, the secular decline in energy reserves, strikes by oil and coal workers, and other economic developments specific to the energy sector".

Hamilton (1983) finds that all but one of the US recessions since WWII have been precede by a dramatic increase in the price of crude petroleum, although this does not mean that oil shocks causes these recessions, there is evidence that oil shocks were a contributing factor in at least some of the US recessions prior to 1972.

Mork (1989) pays particular attention to the possibility of asymmetric responses to oil prices increases and decreases and finds that there exists a statistically significant negative correlation between GDP and oil price increases and a statistically insignificant correlation between GDP and decreases in the real price of oil.

Mork, Olsen and Mysen (1994) show that oil shocks affect the GDP in US, Japan, Germany, Canada, France, UK and Norway; while the effects are the strongest for US, Japan and Norway.

The related empirical studies started by finding a linear negative relationship between oil prices and real activity in oil importing countries. Raymond and Rich (1997) develop a Markov switching model to analyze the relationship between oil price shocks and the GDP growth and find that the principal channel of effect of oil prices is on the mean of low-growth phases of output rather than the transitional probabilities between growth states.

If oil affects real output, increases in oil price depress aggregate stock prices by lowering expected earnings. This suggests that oil prices shocks

should be associated with stock returns. Sadorsky (1999) concludes that changes in oil prices impact economic activity but, changes in economic activity have little impact in oil prices.

Jones and Kaul (1996) conclude that changes in oil prices that granger-precede most economic series, have an effect on output and real stock returns in the United States. Ciner (2001) finds that oil shocks impact stock index returns in a nonlinear fashion.

Today we can read in the newspaper and watch on television that U.K. Brent raises and the stock markets around the world are being affected by this increase in the oil price. If we have a look to the evolution for the oil price from 1989 to now, we observe that in last years oil price is increasing continuously. This paper studies the real impact of these increases in oil price on stock market and compares this reaction of stock markets with the reaction of industrial production to analyze if the stock market reacts more rapidly than industrial production.

This paper analyzes a joint model to study the impact of shocks in oil prices on industrial production and the impact of shocks in oil prices on stock returns. We compare the effect of an increase of oil price on industrial production and on stock returns. We combine Hamilton's (1989) model of recession and Hamilton and Susmel's (1994) model of changes in the ARCH process characterizing stock returns. Following Hamilton and Lin (1996) we hypothesize that there is a single latent variable (the state of the economy) which determines both the mean of industrial production growth and the scale of stock volatility.

So, we think that the mean of industrial production will be determined by the state of the economy and the shocks in oil prices, while the mean of the stock returns will be only affected by shocks in oil prices and the state of the economy only has an effect on the volatility.

This paper investigates too the influence of the oil price on the transition probability from one state of the economy to other, i.e. we relax the assumption in Hamilton (1989) that the state transition probabilities are constant and instead allow them to depend on lagged real oil price increases.

The results demonstrate that oil price has a negative influence on industrial production and on stock returns and they illustrate that the stock market reacts in a stronger way than industrial production to raises in oil price. Oil price has an effect on transition probabilities.

The structure of the paper is as follows: in section 2 we present the model, section 3 shows the empirical results and section 4 concludes.

2 The model

The model for the industrial production, following Hamilton (1989) is as follows:

$$
\begin{aligned}
y_t &= z_t + \mu_{st}. \\
\mu_{st} &= \gamma_{st} + \alpha_1 \times oil_{t-1} + \alpha_2 \times oil_{t-2} + \ldots + \alpha_m \times oil_{t-m}. \\
z_t &= \phi_1 \times z_{t-1} + \phi_2 \times z_{t-2} + \ldots + \phi_q \times z_{t-q} + \epsilon_t.
\end{aligned}
$$

where:

y: monthly growth rate of an aggregate index of industrial production.

Oil: monthly growth rate of oil price.

ϵ_t is assumed to be $i.i.d.$ N(0,σ^2).

In this specification st is an unobserved latent variable that reflects the state of the business cycle. In the general case we allow st to assume one of the K different values represented by the integers (0, 1, 2,..., K). In this particular model, for simplicity we assume that there exist only two states of the business cycle, expansions and recessions.

This model assumes that industrial production follows the nonlinear specification suggested by Hamilton (1989), i.e., the process is subject to discrete shifts in regime—episodes across which the dynamics behavior of the series is markedly different. This specification has been used by many authors and the results show that this model is a good description of the behavior of industrial production[1].

Following Hamilton and Susmel (1994), we establish the next specification for stock returns:

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[1]We have study the specification in which the variance of the growth rate of industrial production is a function of the state of the economy. The model is as follows:

$y_t = z_t + \mu_{st}$;

$\mu_{st} = \gamma_{st} + \alpha_1 * oil_{t-1} + \alpha_2 * oil_{t-2} + \ldots + \alpha_m * oil_{t-m}$;

$z_t = \phi_1 * z_{t-1} + \phi_2 * z_{t-2} + \ldots + \phi_q * z_{t-q} + \sigma_{st}\epsilon_t$; with $\epsilon_t \to$ N(0,1).

The empirical results show that this variance is not statistically significant, so we develop only the case in which the state of the economy affects the mean of industrial production.

$$\begin{aligned}
r_t &= \delta_0 + \delta_1 \times r_{t-1} + \delta_2 \times r_{t-2} + ... + \delta_n \times r_{t-n} + \\
&\quad + \beta_1 \times oil_{t-1} + \beta_2 \times oil_{t-2} + ... + \beta_m \times oil_{t-m} + e_t. \\
e_t &= \sqrt[2]{g_{sd} * u_t}. \\
u_t &= \sqrt[2]{h_t * w_t}. \\
h_t &= \zeta_0 + \zeta_1 * u_{t-1}^2 + \zeta_2 * u_{t-2}^2 + ... + \zeta_s * u_{t-s}^2 + \eta * u_{t-1}^2 * I_{t-1}.
\end{aligned}$$

where:

r: monthly excess returns on S&P 500.

$w_t \rightarrow$ N(0,1).

This model uses an ARCH specification that has been used by many authors in the literature. We have changed this basic specification to improve the model's capacity to describe the stock return series.

We assume that changes in the state of the economy affect the volatility of the stock market. The reason for this assumption is that the tendency of the stock market volatility to exhibit episodic variations, is a well documented feature of this series and, given the limited predictability of stock returns, it is surely a mistake to overparameterice the mean of rt.

In this case sd is an unobserved latent variable that represents the volatility phase of the stock market. For g_{sd} not identically equal to unity, u_t is multiplied by a scale factor g_{sd} representing the current phase sd that characterizes overall stock volatility. The variable u_t is then multiplied by the constant $\sqrt[2]{g_1}$ when the process is in the regime represented by $sd = 1$ and multiplied by $\sqrt[2]{g_0}$ when $sd = 0$. We will normalize g_1 to 1, so g_0 shows us the average variance of stock returns when we are in state 0.

Black (1976) and Nelson (1991) have given evidence that the asymmetric effect of stock price increases and decreases on volatility is a very important feature of the stock return data. For this reason, the error in the specification for stock returns, e_t, follows a L-ARCH process, which introduce the leverage effect. With this structure we are going to study if increases or decreases in the stock price could have asymmetric effects in the volatility.

In the previous specification, we can see that ht is given by

$$h_t = \zeta_0 + \zeta_1 * u_{t-1}^2 + \zeta_2 * u_{t-2}^2 + ... + \zeta_s * u_{t-s}^2 + \eta * u_{t-1}^2 * I_{t-1}$$

for u_{t-1}^2 as specified in table 1 in appendix 2, and

$$I_{t-1} = \left\{ \begin{array}{l} 1 \text{ if } e_{t-1} < 0 \\ 0 \text{ if } e_{t-1} > 0 \end{array} \right\}$$

With this specification for I_{t-1} we observe that if $\eta > 0$, a stock price decrease has a greater effect on subsequent volatility that would a stock price increase of the same magnitude. With this definition for h_t we introduce in the model the leverage effect, which is the possibility that stock prices decreases and increases could have asymmetric effects on subsequent volatility. This parameterization of the leverage effect was proposed by Glosten, Jagannathan and Runkle (1993).

Such a model requires a formulation of the transition probability from one state to another. Following Hamilton (1989), we establish that this probability is given by a K-state Markov chain:

$$Prob(s_t = i | s_{t-1} = j, s_{t-2} = k, \ldots) = prob(s_t = i | s_{t-1} = j) = p_{ji}.$$

We assume that the transition probability only depends on the state in the previous period and it does not depend on the state before one lag. Some authors as Hamilton and Lin (1996) and Diebold and Rudebusch (1990) have used this assumption and it seems to be a good representation of historical experience.

We are going to describe the connection between the phase of the business cycle (st) and the phase of the stock volatility (sd). We study two different cases: in case 1 the phase of the business cycle (st) and the phase of the stock volatility (sd) are the same. In case 2, both states –st and sd- are independent.

Following Hamilton and Lin (1996), we establish that m, n, s and q are equal to 1. For example, if we are in case 1, we will have four states of nature:
$s_f = 1$ if $s_t = 1$ and $s_{t-1} = 1$;
$s_f = 2$ if $s_t = 1$ and $s_{t-1} = 0$;
$s_f = 3$ if $s_t = 0$ and $s_{t-1} = 1$;
$s_f = 4$ if $s_t = 0$ and $s_{t-1} = 0$.

This mean that if we have for example that $s_f=2$, the state of the economy in period t is 1 (we can assume that 1 is expansion and 0 is recession) and the state in period t-1 is 0, this is, we pass from an state of recession to an state of expansion and this change occurs for industrial production and stock returns.

Let P be a matrix whose row j, column i entry is the probability $\text{Prob}(s_f = j|s_{f-1} = i)$

$$P = \begin{pmatrix} p_{11} & p_{11} & 0 & 0 \\ p_{10} & p_{10} & 0 & 0 \\ 0 & 0 & p_{01} & p_{01} \\ 0 & 0 & p_{00} & p_{00} \end{pmatrix}$$

Let $x_t = (y_t, r_t)'$ be a (2x1) vector containing the growth rate of industrial production and the excess return on stocks, and consider the vector process:

$$\begin{aligned} x_t &= \theta_{sf} + \rho_1 * x_{t-1} + \rho_2 * x_{t-2} + \ldots + \rho_q * x_{t-q} + \\ &\quad + \delta_1 * oil_{t-1} + \delta_2 * oil_{t-2} + \ldots + \delta_s * oil_{t-s} + L_{t,sf} \times v_t. \end{aligned}$$

For the case which we are going to study, we can say that ρ_j is a diagonal matrix given by:

$$\rho_j = \begin{pmatrix} \phi_j & 0 \\ 0 & \delta_j \end{pmatrix}$$

In the above equation v_t is assumed to be $N(0, I^2)$, with I^2 being a (2x2) identity matrix. For the other parameters, we have the values in the appendix in table 1 for case 1, in which st and sd are the same.

To compute the parameters for this specification, we will evaluate the log likelihood of the observed data,

$$L = \sum log f(x_t|x_{t-1}, x_{t-2}, \ldots, x_{-q}; \gamma)$$

where

$$\begin{aligned} f(x_t|x_{t-1}, x_{t-2}, \ldots, x_{t-q}, s_f) &= (2\pi)^{-1}|L_t, s_f|^{-1} exp(-1/2 * \xi'_{t,s_f} \xi_{t,s_f}). \\ \xi_{t,sf} &= L_{t,sf}^{-1}(x_t - \theta_{sf} - \rho_1 * x_{t-1} - \ldots - \rho_q * x_{t-q}) \end{aligned}$$

To evaluate the log likelihood we will use the method described by Hamilton (1994), where γ is a vector of population parameters containing the unknown elements of $P, \rho_j, \theta_{sf}, L_{t,sf}$.

The resulting maximum likelihood estimates from above can be used to form an inference about the latent state of the form $\text{Prob}(s_f = 1 | x_t, x_{t-1}, \ldots, x_1; \gamma)$. In case 1 probability of being in a recession is given by the expression,

$$
\begin{aligned}
Prob(s_t \ &= \ 0 | x_t, x_{t-1}, \ldots, x_1; \gamma) = \\
&= \ Prob(s_f = 3 | x_t, x_{t-1}, \ldots, x_1; \gamma) + Prob(s_f = 4 | x_t, x_{t-1}, \ldots, x_1; \gamma).
\end{aligned}
$$

In case 2 probability of being in a recession can be computed as:

$$
\begin{aligned}
Prob(s_t \ &= \ 0 | x_t, x_{t-1}, \ldots, x_1; \gamma) = Prob(s_f = 9 | x_t, x_{t-1}, \ldots, x_1; \gamma) + \\
+ Prob(s_f \ &= \ 10 | x_t, x_{t-1}, \ldots, x_1; \gamma) + Prob(s_f = 11 | x_t, x_{t-1}, \ldots, x_1; \gamma) + \\
+ Prob(s_f \ &= \ 12 | x_t, x_{t-1}, \ldots, x_1; \gamma) + Prob(s_f = 13 | x_t, x_{t-1}, \ldots, x_1; \gamma) + \\
+ Prob(s_f \ &= \ 14 | x_t, x_{t-1}, \ldots, x_1; \gamma) + Prob(s_f = 15 | x_t, x_{t-1}, \ldots, x_1; \gamma) + \\
+ Prob(s_f \ &= \ 16 | x_t, x_{t-1}, \ldots, x_1; \gamma)
\end{aligned}
$$

3   Empirical results

We use monthly data from January 1963 to May 2004.

The transformations that we have done to the data in this analysis are shown in appendix 1.

Here we describe only some of the most important features of the data. Following Hamilton and Lin, we are going to use real stock returns throughout our analysis. We measure the real of return on common stocks as the difference between the S&P 500 and the inflation rate calculated using the consumer price index.

For oil price we use a transformation following Hamilton (1996). He proposed a net oil price increase variable that relates the current price of oil to its value over the previous year rather than the previous month. Specifically the variable is defined to be equal to the percentage change in the current real price of oil from the previous year's maximum if positive and zero otherwise. With this transformation Hamilton improves Mork's modification (1989) to study the asymmetric effects of increases and decreases of oil price on the economy. This calculation makes clear that most of the individual price increases since 1986 were simply corrections to earlier declines. The reason is that if someone wants a measure of how unsettling an increase in the price of

oil is likely to be for the spending decisions of consumers and firms, it seems more appropriate to compare the current price of oil with where it has been over the previous year rather than during the previous month alone.

Table 2 shows the results for cases 1 and 2, under the following conditions: $q = m = s = 1$ and we have only two phases of the business cycle, expansion and recession. We will impose that $\zeta_o > 0$ and ζ_1 and $\eta \geq 0$; with this restriction we assure that ht is going to be positive and the variance in the second equation will be positive too. For this last affirmation we need the condition that g_0 is going to be positive too.

In case 1 equations share the same state of the economy, this is, case 1 imposes the restriction that $p_{sd} = p_{st}$. Case 1 allows for dependence between r_t and y_t through their common dependence on the unobserved state st. We can see that oil price has a negative and statistically significant effect on industrial production ($\alpha_1 = -0.0056$) but the negative effect of oil price is stronger on stock returns ($\beta_1 = -0.017$). So, in current period, the effect of shocks in oil prices on stock returns is three times higher than the effect on industrial production, but after three periods the effect changes and it is two times higher on industrial production than on stock returns.

This negative relation between oil price increase and stock returns could be expected because, as we have said before, oil price increases are bad news in oil importing countries since oil is a very important resource for these nations. This increase in the price of the resources will raise firms' costs and will reduce the expected earnings. All these effects could affect the stock returns in a negative way.

The reason for this stronger effect of oil price on stock returns than on industrial production is that the stock market reacts more rapidly than the industrial production to changes in the economic situation. When oil price increases, the stock market reacts immediately to this situation but the industrial production is not as flexible as stock market and the immediate reaction to the change is lower.

We observe that the parameter ζ_1 from the expression for h_t converges to zero. We dropped the parameter ζ_1 from the model, concluding that, for this data set, the only arch effects are those caused by downwards movements in stock prices, as captured by the parameter η.

Table 2: Results for cases 1, 2 and 4.

Table 2 shows the maximum likelihood estimates for the model:

$y_t = z_t + \mu_{st}$;

$\mu_{st} = \gamma_{st} + \alpha_1 \times oil_{t-1} + \alpha_2 \times oil_{t-2} + ... + \alpha_m \times oil_{t-m}$;

$z_t = \phi_1 \times z_{t-1} + \phi_2 \times z_{t-2} + ... + \phi_q \times z_{t-q} + \epsilon_t$;

$r_t = \delta_0 + \delta_1 \times r_{t-1} + \delta_2 \times r_{t-2} + ... + \delta_n \times r_{t-n} + \beta_1 \times oil_{t-1} + \beta_2 \times$
$\times oil_{t-2} + ... + \beta_m \times oil_{t-m} + e_t$;

$e_t = \sqrt[2]{g_{sd} * u_t}$;

$u_t = \sqrt[2]{h_t * w_t}$;

$h_t = \zeta_0 + \zeta_1 * u_{t-1}^2 + \zeta_2 * u_{t-2}^2 + ... + \zeta_s * u_{t-s}^2 + \eta * u_{t-1}^2 * I_{t-1}$;

where y_t is the industrial production, z_t is the stock return and oil_t is the oil price in period t. ϵ_t is assumed to be $i.i.d.$ $N(0,\sigma^2)$ and w_t is assumed to be $i.i.d.$ $N(0,1)$. Standard errors are in parenthesis. The transition probabilities are constant; they do not depend on oil prices. In case 1 both equation share the state of the economy. In case two the states of the economy are independent. Case 4 is a mixture of cases 1 and 2 with ψ being the weight of case 1 and $(1 - \psi)$ the weight of case 2.

PARAMETERS	CASE 1	CASE 2	CASE 4
γ_1	-0.003(0.001)	0.004 (0.0004)	0.004 (0.0004)
γ_0	0.004(0.0004)	-0.008 (0.001)	-0.006 (0.001)
ϕ_1	0.18(0.05)	0.18 (0.04)	0.14 (0.04)
α_1	-0.005(0.001)	-0.006 (0.0015)	-0.005 (0.002)
δ_0	0.004(0.002)	0.004 (0.002)	0.005 (0.002)
δ_1	0.11(0.05)	-0.003 (0.06)	-0.015 (0.004)
β_1	-0.02(0.009)	-0.02 (0.01)	-0.02 (0.008)
g_0	0.31(0.05)	0.21 (0.04)	3.93 (0.69)
σ	0.006(0.0002)	0.006 (0.0002)	0.006 (0.0002)
ζ_0	0.004(0.0007)	0.002 (0.0001)	0.001 (0.0002)
ζ_1	$6.69*10^{-11}$(0.03)	$4.55*10^{-12}$ (0.11)	$6.54*10^{-11}$ (0.08)
η	0.06(0.008)	0.17 (0.14)	0.11 (0.09)
$Prob(rec)IP$	0.86(0.05)	0.81 (0.07)	0.86 (0.06)
$Prob(exp)IP$	0.96(0.015)	0.97 (0.01)	0.97 (0.01)
$Prob(rec)SR$	—	0.98 (0.07)	$6.95*10^{-11}$ (2.41)
$Prob(exp)SR$	—	0.96 (0.02)	$4.87*10^{-12}$ (2.38)
ψ	—	—	0.82 (0.36)
$log-likelihood$	2628.17	2633.28	2638.22

Case 2 imposes that the state governing the industrial production (st) and the state governing stock volatility (sd) are independent, this is, in this case r_t and y_t are completely independent. We observe that the effect of oil price on industrial production is, as in the case above, negative and statistically significant ($\alpha_1 = -0.0064$) but a little stronger than in case 1. Here, we can see too that the influence of oil price on stock returns is negative and statistically significant ($\beta_1 = -0.01734$) and is more or less three times higher than the effect of oil price on industrial production.

This case shows the same situation than before, i.e., ζ_1 converges to zero. So here we say that, as in the case 1, the only ARCH effect is given by the parameter η.

We have tried to compare these two models to see which one is better. To study this problem, we have followed a method given by Bengoechea and Perez Quirós (2004). The idea is the following, we have two extreme situations; in the first one we estimate a model where industrial production and stock returns share the same state of the economy. In the second situation the state governing the industrial production (st) and the state governing stock volatility (sd) are independent.

Assuming that we have only two states of economy, expansion and recession, we have four basic states:

$s_t = 1, s_d = 1$;
$s_t = 1, s_d = 0$;
$s_t = 0, s_d = 1$;
$s_t = 0, s_d = 0$.

The probability of being in one of these basic states depends on the situation in which we are. If we are in the first situation, where the variables share the state of the economy, the probability would be the following,

$$
\begin{aligned}
P(s_t &= 1, s_d = 1) = P(s_t = 1) \\
P(s_t &= 1, s_d = 0) = 0 \\
P(s_t &= 0, s_d = 1) = 0 \\
P(s_t &= 0, s_d = 0) = P(s_t = 0).
\end{aligned}
$$

On the other hand, the probability of being in these four states when the states of the economy are independent is as follows,

$$\begin{aligned}
P(s_t &= 1, s_d = 1) = P(s_t = 1) * P(s_d = 1) \\
P(s_t &= 1, s_d = 0) = P(s_t = 1) * P(s_d = 0) \\
P(s_t &= 0, s_d = 1) = P(s_t = 0) * P(s_d = 1) \\
P(s_t &= 0, s_d = 0) = P(s_t = 0) * P(s_d = 0).
\end{aligned}$$

The only difference between sharing or not the state of the economy is in the form of the transition probabilities. We want to study what is the best model. The true data maybe would be between these two extreme situations. To find this intermediate point Bengoechea and Pérez Quirós propose the following transition probabilities:

$$\begin{pmatrix} P(s_t{=}1, s_d{=}1) \\ P(s_t{=}1, s_d{=}0) \\ P(s_t{=}0, s_d{=}1) \\ P(s_t{=}0, s_d{=}0) \end{pmatrix} = \psi \begin{pmatrix} P(s_t{=}1) \\ 0 \\ 0 \\ P(s_t{=}0) \end{pmatrix} + (1{-}\psi) \begin{pmatrix} P(s_t{=}1) * P(s_d{=}1) \\ P(s_t{=}1) * P(s_d{=}0) \\ P(s_t{=}0) * P(s_d{=}1) \\ P(s_t{=}0) * P(s_d{=}0) \end{pmatrix}.$$

In this case the most important parameter is ψ. If ψ is close to 1, this shows that we are closer to the assumption of sharing the state of the economy. If, on the contrary, we are closer to the independence of the states, the ψ will be around 0.

We estimate this last specification and the results are shown in the third column of table 2. If we have a look to the results for this last case we can see that ψ is close to 1 ($\psi = 0.8276$), so this mean than the assumption that they share the business cycle is closer to reality than the independence of the business cycle.

Previous cases impose that the transition probabilities are constant in the sense that they do not depend on any variable. Case 3 develops the model as in case 1 but assuming that the transition probabilities depend on one lag of the oil price. What we assume is that

$$\begin{aligned}
Prob(s_t &= 1 | s_{t-1} = 1) = p_t = \lambda_0 + \lambda_1 * oil_{t-1} \\
Prob(s_t &= 0 | s_{t-1} = 0) = q_t = \tau_0 + \tau_1 * oil_{t-1}
\end{aligned}$$

Results for this last case are shown in table 3.

Table 3 shows the maximum likelihood estimates for the model:

$y_t = z_t + \mu_{st}$

$\mu_{st} = \gamma_{st} + \alpha_1 * oil_{t-1} + \alpha_2 * oil_{t-2} + \ldots + \alpha_m * oil_{t-m}$

$z_t = \phi_1 * z_{t-1} + \phi_2 * z_{t-2} + \ldots + \phi_q * z_{t-q} + E_t$

$r_t = \delta_0 + \delta_1 * r_{t-1} + \delta_2 * r_{t-2} + \ldots + \delta_n * r_{t-n}$

$\qquad + \beta_1 * oil_{t-1} + \beta_2 * oil_{t-2} + \ldots + \beta_m * oil_{t-m} + e_t$

$e_t = \sqrt[2]{g_{sd}} * u_t$

$u_t = \sqrt[2]{h_t} * w_t$

$h_t = \zeta_0 + \zeta_1 * u_{t-1}^2 + \zeta_2 * u_{t-2}^2 + \ldots + \zeta_s * u_{t-s}^2 + \eta * u_{t-1}^2 * I_{t-1}$

where y_t is the industrial production, z_t is the stock return and oil_t is the oil price in period t. Et is assumed to be i.i.d. $N(0,\sigma^2)$ and w_t is assumed to be i.i.d. $N(0,1)$. Standard errors are in parenthesis. The transition probabilities are given by $Prob\,(s_t = 1|s_{t-1} = 1) = p_t = \lambda_0 + \lambda_1 * oil_{t-1}$ and $Prob\,(s_t = 0|s_{t-1} = 0) = q_t = \tau_0 + \tau_1 * oil_{t-1}$.

PARAMETERS	CASE 3
γ_1	-0.0022 (0.001)
γ_0	0.004 (0.0005)
ϕ_1	0.22 (0.05)
α_1	-0.004 (0.002)
δ_0	0.005 (0.002)
δ_1	-0.09 (0.05)
β_1	-0.02 (0.01)
g_0	0.29 (0.06)
σ	0.006 (0.0002)
ζ_0	0.004 (0.0007)
ζ_1	5.69*10-11 (0.062)
η	0.04 (0.012)
$Prob(rec)$ constant	-3.27 (0.77)
$Prob(exp)$ constant	6.45 (1.52)
$Prob(rec)\ \lambda_1$	7.92 (2.30)
$Prob(exp)\ \tau_1$	-7.61 (1.79)
ψ	
$log-likelihood$	2625.21

The results in this case show that the assumption about the transition probability is good because the coefficients of oil price in the probabilities are statistically significant. We see that oil price effect on transition probability from expansion to expansion is negative and statistically significant (-7.609), this mean that an increase in oil price reduce the probability of remaining in expansion. For the transition probability of remaining in a recession, the effect of oil price is positive and statistically significant (7.906), so we can say that if oil price increases the probability of continuing in a recession will be higher.

These results are as we could expect because from an economic point of view it is very intuitive to think that if oil price increases, this affect to the economy and the probability of remaining in an expansion falls.

Related to the influence of oil prices on industrial production and stock returns, we observe a behavior similar to case 1; there exists a negative and statistically significant influence of oil prices on both variables, although the effect of oil price on stock returns is higher than on industrial production.

Figure 1 shows the raw data for industrial production and stock returns used in this analysis. The bottom panel plots the probability of being in recession that we have computed in case 1.The shaded areas shows NBER recessions. The idea is that in recession the industrial production is lower than in expansions and the stock market volatility will be higher. The correspondence between econometric inference and the NBER dating of economic recessions is remarkable.
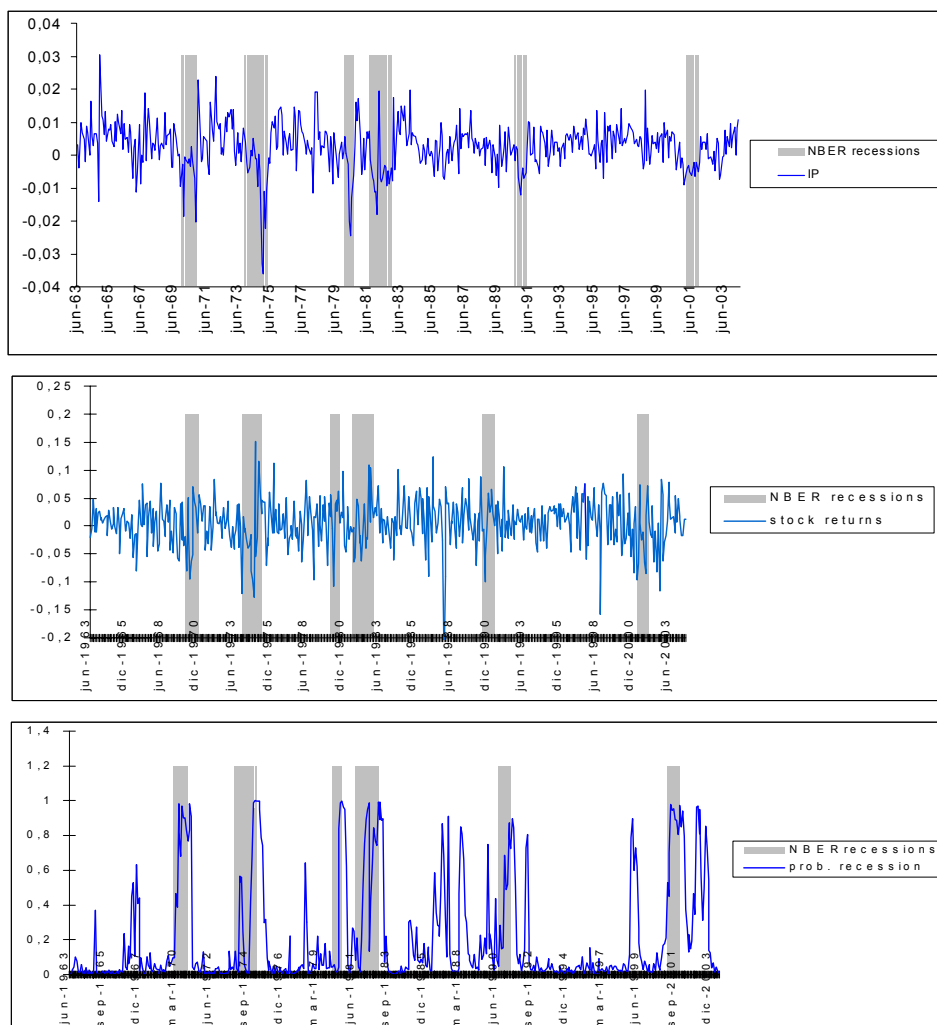
Figure 1: (*a*) Rate of growth of industrial production (monthly rate)
(*b*) excess return on S&P500 stock price index (monthly rate)
(*c*) probability of being in recession at date *t*
(*) Shaded areas show NBER recessions.

4 Conclusions

This paper analyzes the relationship between oil price and the stock market and between oil price and industrial production. The aim of this work is to study which relationship is stronger, i.e., which variable reacts more rapidly to increases in oil price.

For this purpose, we establish a specification assuming that there exists a single latent variable (the state of the economy) which determines the mean of industrial production growth and the scale of the stock returns volatility.

Results show that an increase in oil price has a negative effect on industrial production and on stock market. In the immediate period after the shock, stock returns have a reaction to increases in oil price three times higher than the reaction of industrial production. However, four periods after the shift, this reaction will vary and the response of industrial production to changes in oil price will be two times higher than the response of stock returns to these variations in oil price. These results illustrate that stock market reacts more rapidly than the industrial production to raises in oil price, but in a long period, the effect on industrial production will be higher than on stock returns.

Finally, empirical results prove that increases in oil price have a negative effect on the probability of remaining in expansion and they have a positive effect on the probability of being in a recession.

Appendix 1

We summarize briefly the transformations applied on variables in the following table 1.

Variable	Raw data series	Transformations used
inflation	Consumer price index	First differences in the logarithms of the index
Oil shocks	UK Brent	
Stock returns	Aggregate stock market indexes (S&P 500)	First differences in the logarithms of the index
Real stock returns		Stock returns-inflation
Industrial production	Index of industrial production	First differences in the logarithms of the index

Appendix 2

Table 1: Meaning of parameters for case 1.

Meaning of parameters in the case where the equations for industrial production and for stock returns share the state of the economy.

s_f	θ_{sf}	$L_{t,sf}$	$u^2_{t-1,sf}$
1	$\gamma_1 - \phi_1 * \gamma_1$	$\sigma\ 0$	e^2_{t-1}/g_1
	δ_0	$0\ \sqrt[2]{g_1 * h_t}$	
2	$\gamma_0 - \phi_1 * \gamma_1$	$\sigma\ 0$	e^2_{t-1}/g_0
	δ_0	$0\ \sqrt[2]{g_1 * h_t}$	
3	$\gamma_1 - \phi_1 * \gamma_0$	$\sigma\ 0$	e^2_{t-1}/g_1
	δ_0	$0\ \sqrt[2]{g_0 * h_t}$	
4	$\gamma_0 - \phi_1 * \gamma_0$	$\sigma\ 0$	e^2_{t-1}/g_0
	δ_0	$0\ \sqrt[2]{g_0 * h_t}$	

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